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LOW THRUST VEHICLE CONCEPT STUDY

GENERAL DYNAMICS
Convair Division

GDC-ASP-80-010

LOW THRUST VEHICLE CONCEPT STUDY

26 September 1980

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Prepared by
Advanced Space Programs
GENERAL DYNAMICS CONVAIR DIVISION
San Diego, California

FOREWORD

This report documents the results of Contract NAS8-33527, Task 7 — "Low Thrust Vehicle Concept Study". This study was conducted over a 9-month period from September 1979 to May 1980. The NASA/MSFC Program Manager was D. R. Saxton. The General Dynamics Program Manager was W. J. Ketchum.

In addition to the program managers, many General Dynamics Convair personnel contributed to the study. The key individuals and their contributions are:

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R. Maffucci	Propellant Acquisition
S. Maki	Avionics/Power
F. Merion	Thermodynamics
C.D. Pengelley	Structural Dynamics
R.C. Risley	Costs, Schedules
E.I. Seiden	Weights
L.E. Siden	Conceptual Designs
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All data in this report are presented in the English System.

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SUMMARY

Large Space Systems (LSS) such as the Geostationary Communications Platform (GP) and Space Based Radar (SBR) are planned for the late 1980's and the 1990's. These are "next generation" spacecraft as large as 600 feet in size and up to 25,000 pounds in weight. Forty-seven such missions have been forecast (1987-2000) in the OTV Concept Definition Study mission model, reference 1.

It will be advantageous to deploy and check out these expensive spacecraft in Low Earth Orbit (LEO) while still attached to the Orbiter, so any problems can be fixed, even by EVA, if necessary. The Space Shuttle will offer this opportunity. Once deployed and functioning, low acceleration during transfer to higher orbits (GEO) would minimize stresses on the structure, allowing larger size and/or lower weight spacecraft.

This report documents results of a "Low Thrust Vehicle Concept Study" conducted over a 9-month period, September 1979-May 1980, to investigate and define new low thrust chemical (hydrogen-oxygen) propulsion systems configured specifically for low-acceleration orbit transfer of large space systems. This study for NASA/MSFC was conducted in coordination with low-thrust engine/propulsion studies/technology efforts at NASA/LeRC and NASA/MSFC. The results of this systems/concept study are intended to help guide the propulsion technology effort already underway and to provide additional data to compare new, low-thrust chemical propulsion systems with other propulsion approaches.

Study results indicate that it is cost-effective and least risk to combine the OTV and stowed spacecraft in a single 65K Shuttle. Inspection of the mission model shows that there are 25 such missions, starting in 1987. Multiple Shuttles (LSS in one, OTV in another) result in only a 20% increase in LSS (SBR) diameter over single Shuttle launches.

Synthesis and optimization of the LSS characteristics and OTV capability resulted in determination of the optimum thrust-to-weight ratio (T/W) and thrust level.

For the Space Based Radar with radial truss arms (center thrust application), the optimum T/W (maximum) is 0.1, giving a thrust of 2,000 lb.

For the annular truss (edge-on thrust application) the structure is not as sensitive.

For the geoplatform, optimum T/W is 0.15 (3,000 lb thrust).

The effects of LSS structure material, weight distribution, and unit area density were also evaluated. In general, results in the 1-3K thrust range were relatively insensitive.

A constant-thrust, 9-burn trajectory gives better performance (and is less sensitive than constant acceleration-variable thrust, 2 burn) and eliminates increased engine complexity (multiple low-thrust levels). The overall impact of these 2 modes of operation has yet to be evaluated; however, analysis of OTV insulation and pressurization requirements has determined that propellant tank vapor residuals/pressures are little affected by the number of burns or engine thrust level. Increased mission duration (80 versus 60 hours total time including checkout, deployment, transfer) makes little difference.

Engine thrust transient results in a dynamic factor of approximately 2. This can be reduced by using a slow, or a stepped thrust transient, but either complicates the engine, and results in little improvement (3%) in the LSS size.

Distributed thrust, in addition to complicating the design of the OTV and LSS, increases dynamic loading on the structure due to the difficulty in exact phasing of multiple thrusters.

To maximize the Orbiter payload bay volume available for the large space structure, a torus LO_2 tank is used to achieve minimum OTV length. For the 65K Shuttle, the OTV is ~18 feet long, having a propellant loading of 38,000 lb and a burnout weight of 6,000 lb. Considering the Orbiter support equipment and rotation, over 35 feet is allowed for payload length. The c.g. of the OTV, payload, and support equipment fall within the Shuttle constraints. All propellants are dumped overboard in the event of an abort.

The technology of torus tanks was investigated and a unique acquisition device was conceived that minimizes residuals no matter what the thrust offset. Only one propellant outlet is required, and no separate sumps are needed. Thrust transient analysis indicated that no negative accelerations occur on the propellant during engine operations.

Several types of engines were considered; a new low-fixed thrust pump-fed engine and a low-thrust (pumped idle) mode of the OTV engine. Using 1500-lb thrust at 455 sec Isp and a 9-burn trajectory, a payload mass of ~16,000 lb can be delivered to GEO.

CONCLUSIONS

Based on the groundrules of this study, an optimized low-thrust OTV configured specifically for orbit transfer of large space systems has been defined. The following conclusions are made:

- Engine for an optimized low thrust stage
  - Very low thrust (<1 K) not required.
  - 1-3 K thrust range appears optimum.
  - Thrust transient not a concern.
  - Throttling probably not worthwhile.
  - Multiple thrusters complicate OTV/LSS design and aggravate LSS loads.

- Optimum vehicle for low acceleration missions
  - Single Shuttle launch (LSS and expendable OTV) most cost-effective and least risk.
  - Multiple Shuttles increase LSS (SBR) diameter 20%.
  - Short OTV (which maximizes space available for packaged LSS) favors use of torus tank.
  - Propellant tank pressures/vapor residuals little affected by engine thrust level or number of burns.

RECOMMENDATIONS

- Further study
  - Revise results as new mission and spacecraft data become available (especially as the Geoplatform design evolves).
  - Reevaluate study results as LeRC low-thrust engine studies produce design concepts and cost data.
  - Coordinate with OTV study to compare total mission model requirements and costs of a dedicated low thrust system vs. a conventional OTV operating in the pumped-idle mode.
  - Further evaluate benefits of deploying LSS at LEO vs. GEO.
  - Evaluate how Centaur (with idle mode) could satisfy initial requirements.

- Technology development
  - Hardware R&D is necessary for the engines and vehicle subsystems (low-thrust engine options, torus tank, acquisition, insulation) in order to utilize the dedicated low-thrust system.

1

INTRODUCTION

Many of the large space systems that have been identified as candidates for transportation to geosynchronous orbit are deployed at low earth orbit and are very sensitive to and have minimum capability to withstand acceleration loads during transfer to higher orbits. Because the real requirements and constraints concerning accelerations are currently little known, the effects on propulsion of a wide range of accelerations were investigated. This study investigated and defined low-thrust chemical propulsion systems configured specifically for low-acceleration orbit transfer of large space systems.

1.1 OBJECTIVES

The specific objectives of this study were:

a. Characterize missions which require or benefit from low-thrust orbital transfer.

b. Identify, define, evaluate, and compare candidate low-thrust liquid propulsion orbital transfer stage/vehicle concepts.

c. Investigate payload/vehicle interactions and design implications.

d. Determine propulsion/system characteristics having the greatest influence upon system suitability/capability.

e. Identify and describe propulsion technology requirements.

1.2 STUDY APPROACH

This study was conducted in six major parts over a 9-month period.

During the study, missions and payloads were analyzed to select representative large space systems and their design and operational characteristics which are impacted by the orbit transfer system.

Candidate low-thrust propulsion system concepts and their characteristics were generated to meet the large space systems mission requirements.

The performance capability of the candidate low-thrust propulsion system concepts were analyzed over a wide range of maximum payload acceleration levels.

Interactions of low-thrust propulsion concepts and mission operations with the candidate payload configurations were analyzed to determine and quantify mutual design implications.

The propulsion system characteristics which are the design drivers and have the greatest influence upon the system suitability/capability were identified.

A baseline OTV concept was identified and defined to the conceptual level.

Engine/propulsion and unique subsystem requirements were identified for technology/component planning.

Based on the conceptual-level definition of the propulsion system elements, cost estimates were developed, and milestones and major events were identified for development and production.

2

MISSION/PAYLOAD DEFINITION

Missions and payloads were analyzed to select representative large space systems and their design and operational characteristics which are impacted by the orbit transfer system.

2.1 POTENTIAL MISSIONS/PAYLOADS FOR LOW-THRUST PROPULSION

Mission planning (NASA and DOD) information (reference 1) was used to identify potential low thrust missions, payload characteristics, transportation needs, and schedule requirements. Table 2-1 summarizes these data.

Table 2-1. Potential missions/payloads for low-thrust propulsion.

	NUMBER	IOC	
GEO-platform Demo - 12,500 lb × 25 ft	1	1987	Nominal Model
GEO-platform - 15,000 lb × 25 ft	12	1992	
Space Based Radar			
Polar - 10,000 lb × 25-35 ft	8	1988	
GEO - 15,000-25,000 lb × 60 ft	2	1991	
DOD Class 2 - 12,000 lb × 20 ft	4	1990	
DOD Class 3 - 25,000 lb × 25 ft	8	1992	
Pers Comm - 54,000 lb (3 parts) each - 18,000 lb × 60 ft	12	1993	
	47		
X-ray telescope/Gravity wave interferometer (space fab)		1997	Max Model
Solar Power Demo (space fab)		1995	

2.2 OTV REQUIREMENTS

From these data, the range of requirements imposed on the OTV was determined. Figure 2-1 shows that for payload IOC's in the first 5 years of LSS operations (1987-1992), single Shuttle launches are sufficient.

Starting in 1991, longer and heavier payloads require multiple Shuttle operations

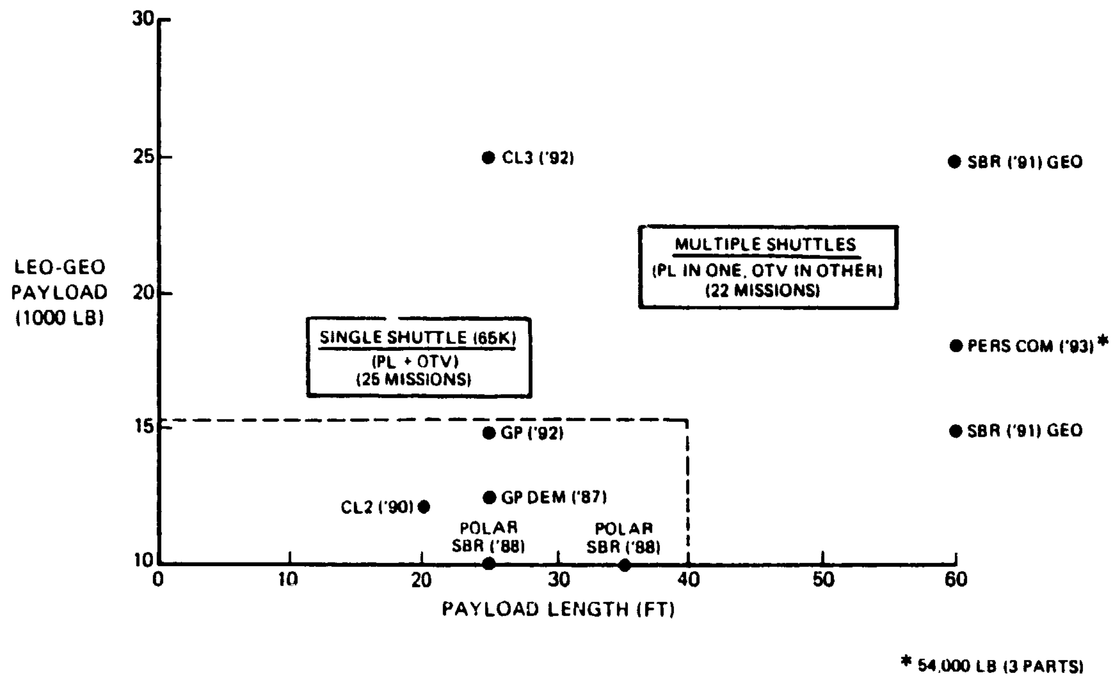


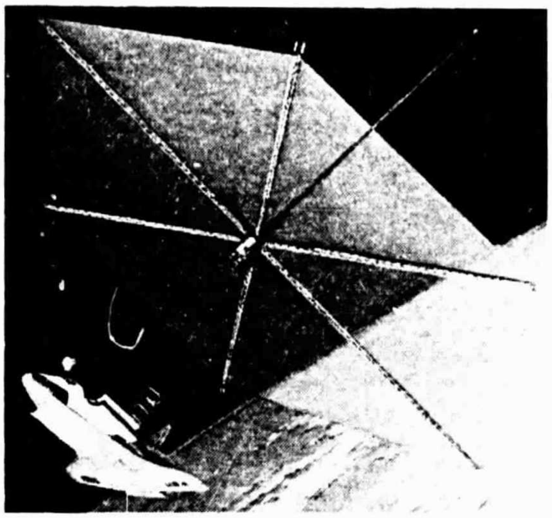
Figure 2-1. Payload allocation.

2.3 SELEC'_ ;D PAYLOAD CHARACTERISTICS

The Geoplatform Communication Antenna System and the Space-Based Radar Antennas (shown in Figure 2-2) are the leading near term missions. These were selected for analysis. Table 2-2 shows that the mission drivers are: 1987 IOC, 35 ft payload, 15,000 lb payload, and geosynchronous mission.

A solar power array was initially considered but was determined to be an unlikely candidate for low thrust chemical propulsion. (See Section 2.3.3.)

SPACE BASED RADAR



GEOPLATFORM

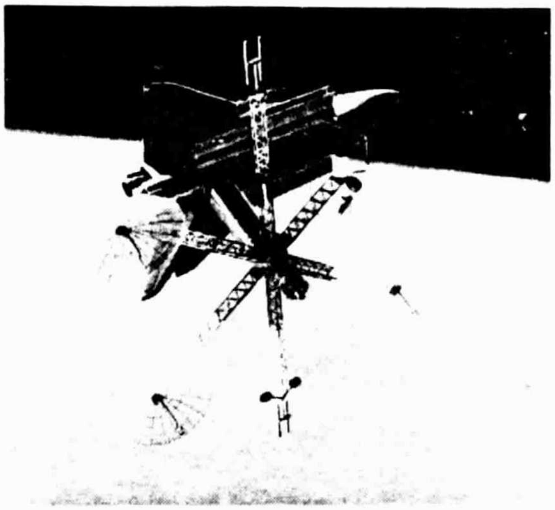


Figure 2-2. Missions/payloads.

Table 2-2. Design and operational characteristics of selected payloads.

	SBR		GP	
	POLAR	GEO	EXPER	OPR
DESIGN CHARACTERISTICS				
WEIGHT (LB)	10,000	15,000-25,000	12,500	15,000 (NOM)
STOWED LENGTH (FT)	25-35	60	25	25
OPERATIONAL CHARACTERISTICS				
MISSION	5600 N. MI. POLAR	GEO	GEO	GEO
IOC	1988	1991	1987	1992
FUNCTION	AIRCRAFT SHIP, GROUND VEHICLE SKIN TRACKING	SAME	ADVANCED COMMUNICATION AND EARTH OBSERVATION	ADVANCED COMMUNICATION AND EARTH OBSERVATIONS
LIFE	10 YR	10 YR	5 YR	16 YR (NOM)
SERVICING	NO	NO	TEST	EVERY 1-1/2 YR

IMPACTED BY OTV   REF: NASA/MSFC 29 FEB 1980

SELECTED MISSIONS ARE THE GEOPLATFORM AND SPACE BASED RADAR. DRIVING REQUIREMENTS ARE: 1987 IOC; 25-35 FT PAYLOAD LENGTH; 15,000 LB PAYLOAD WEIGHT TO GEOSYNCHRONOUS ORBIT.

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2.3.1 SPACE BASED RADAR. The phased-array Space Based Radar concept is shown in Figure 2-3. Two LSS versions being considered by GDC for the SBR are the tetrahedral truss (arm) and the tetrahedral truss (ring).

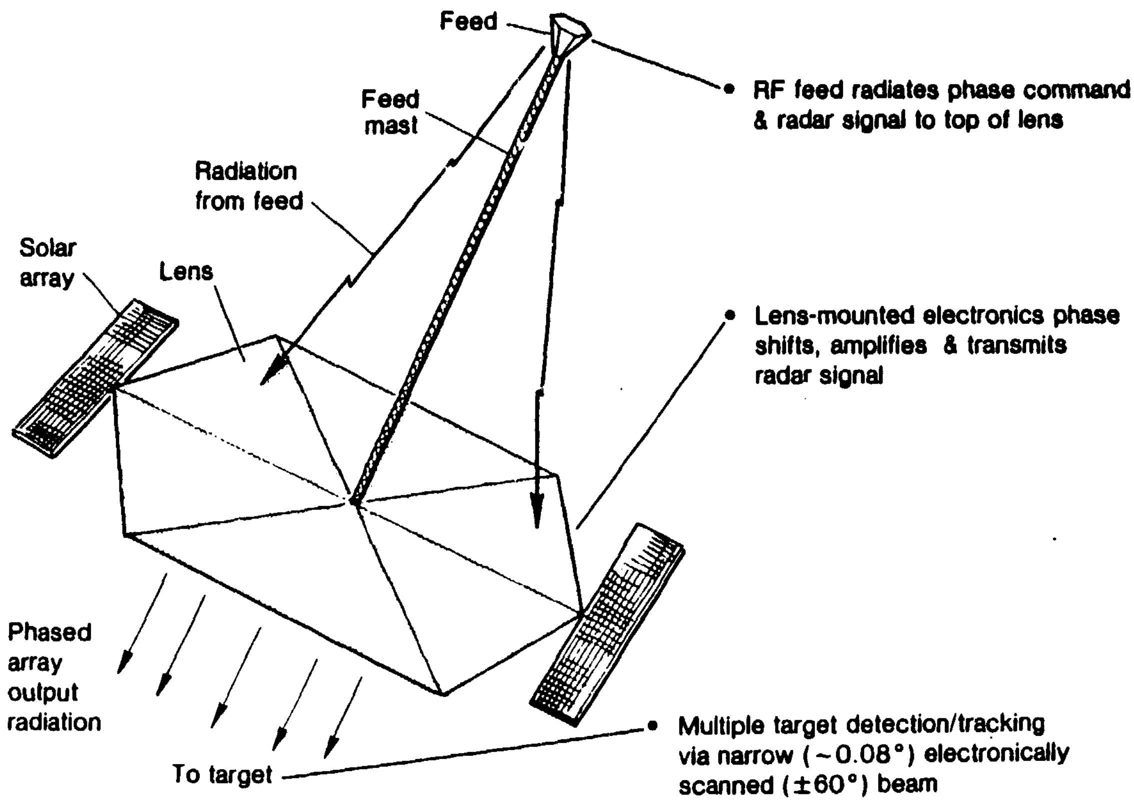


Figure 2-3. Space based phased-array radar concept.

a. Mission goals
   1. Preclude need for expensive upkeep of dew line and AWACS flights.
   2. Provide earlier advance warning.

b. Background
   1. Ten years of feasibility studies of ocean surveillance sensors.
   2. "On-orbit assembly" studies for SAMSO in 1978 (reference 2).
   3. DARPA technology underway, including new GDC lens study.
   4. Recent NASA/MSFC RFP for flight experiment of large deployable antenna.

c. Concepts
   1. Polar Orbit
      (a) Approximately 200 ft diameter gives good resolution
      (b) 6 to 12 spacecraft give coverage

(c) IOC could be as early as 1988

(d) Each spacecraft weighs ~10,000 pounds and requires about 25-35 ft stowed length.

2. GEO orbit

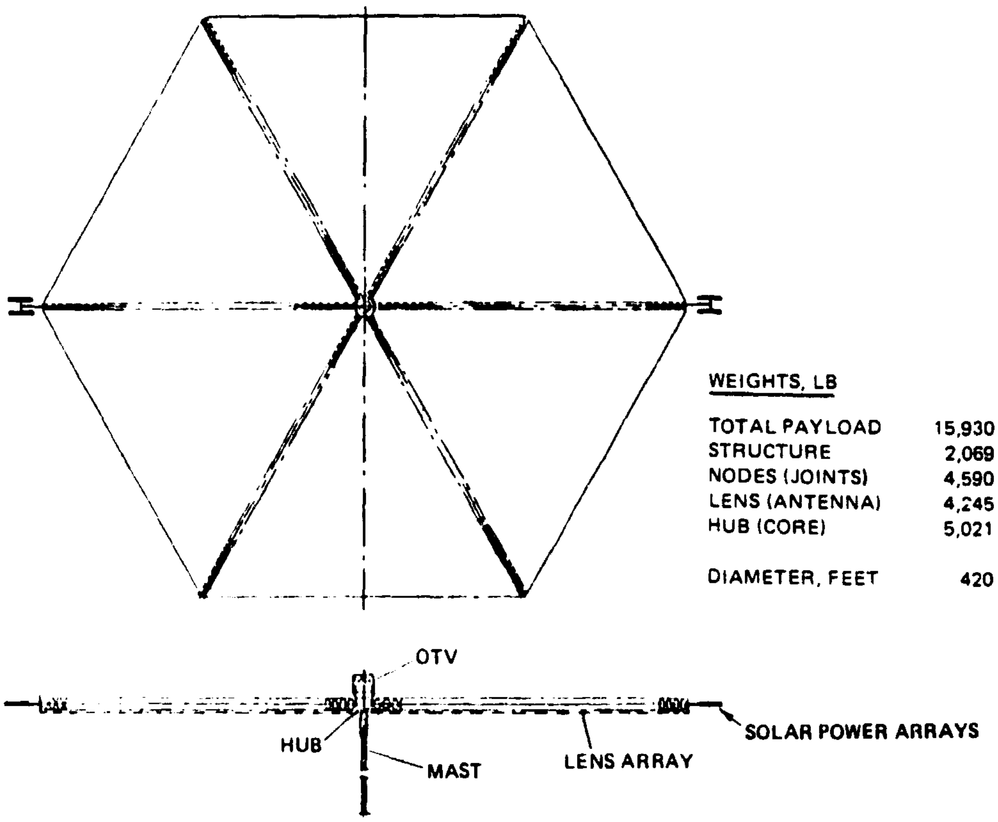
(a) 300 to 600 ft diameter needed for resolution.

(b) 1 or 2 spacecraft required

(c) IOC probably would follow polar-orbit concept

(d) Each spacecraft weighs 15,000-25,000 pounds and requires about 60 ft stowed length

2.3.1.1 Tetrahedral Truss (Arm). The tetrahedral truss (arm) concept is shown in Figure 2-4. Packaging of the SBR and OTV in the orbiter is shown in Figure 2-5.



THIS CONCEPT WAS DEFINED IN DETAIL BY GDC DURING OOA STUDIES FOR THE AIR FORCE

Figure 2-4. Tetrahedral truss arm space-based radar.

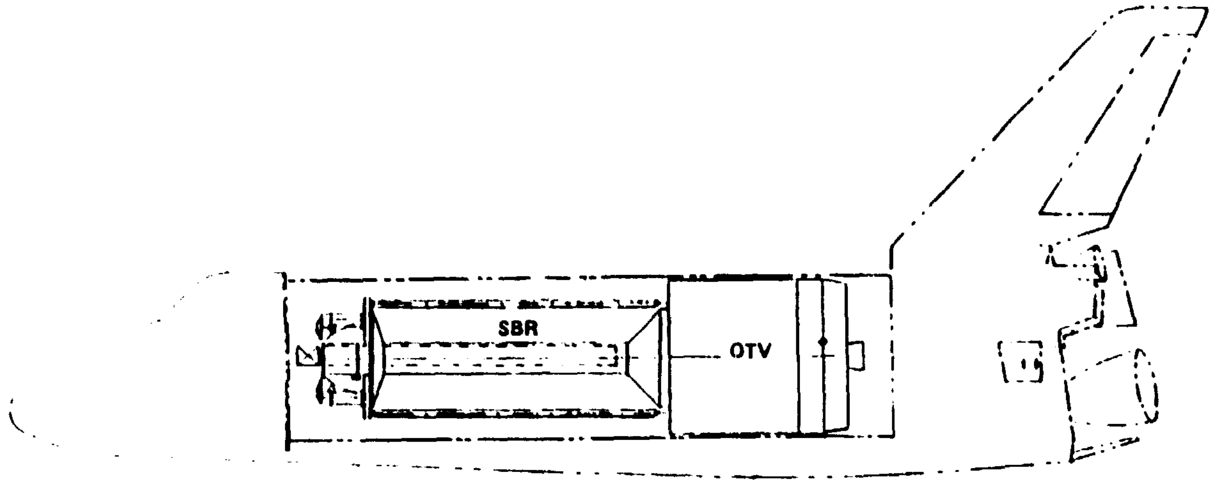


Figure 2-5. SBR and OTV in orbiter.

Six radial expandable truss structures support an active lens array having hexagonal flat pattern. The hub to which these truss structures is attached also mounts an antenna-feed support boom. Packages such as solar arrays, attitude controllers, expendables, and receiver/transmitter equipment are located at either the truss ends or at the hub. The OTV is also attached to the hub and its propulsion thrust vector is normal to the plane of the lens array.

Deployment of the tetrahedral truss (arm) concept is shown in Figure 2-6. The OTV is located at the center of the six-arm truss and thrust is applied normal to the truss and array.

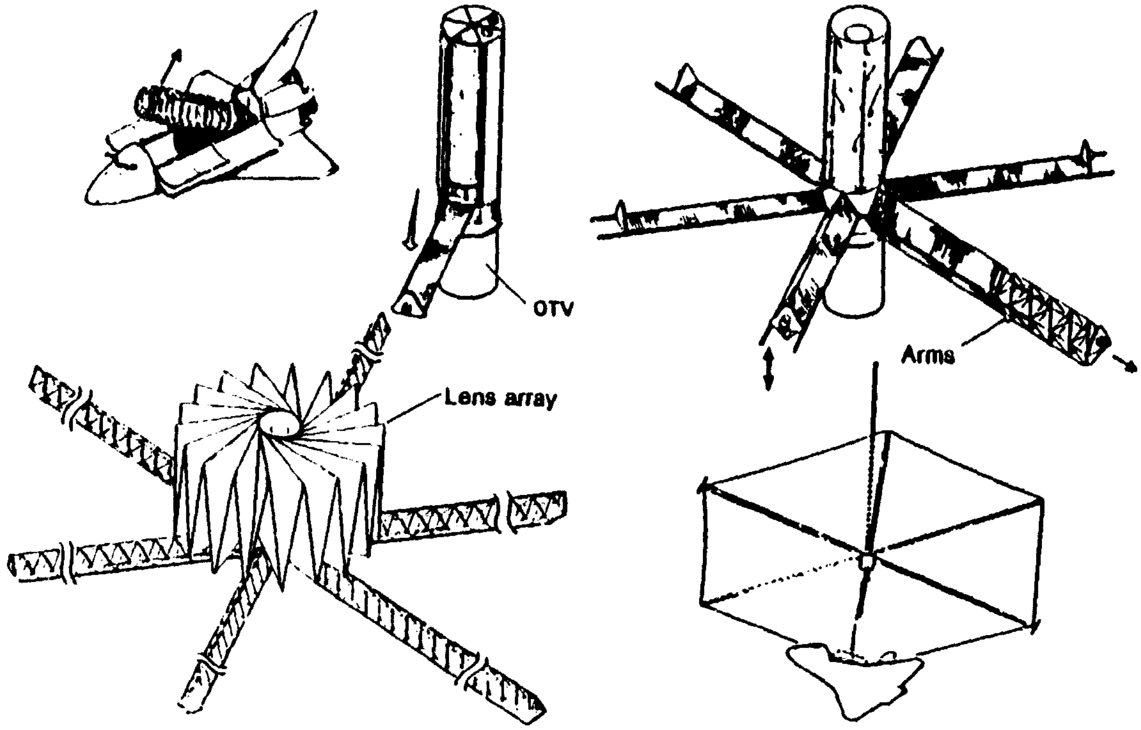


Figure 2-6. Tetrahedral truss arm deployment sequence.

The tetrahedral truss under development by GDC for LSS applications (Figure 2-7) has been selected as the basic structural element in the space-based radar. A prototype deployable truss has been manufactured of graphite/epoxy (GY70/X-30) tubular members with aluminum end fittings, hinges, and hubs.

A principal feature of the beam lies in its ability to accomplish controlled, bay-by-bay deployment.

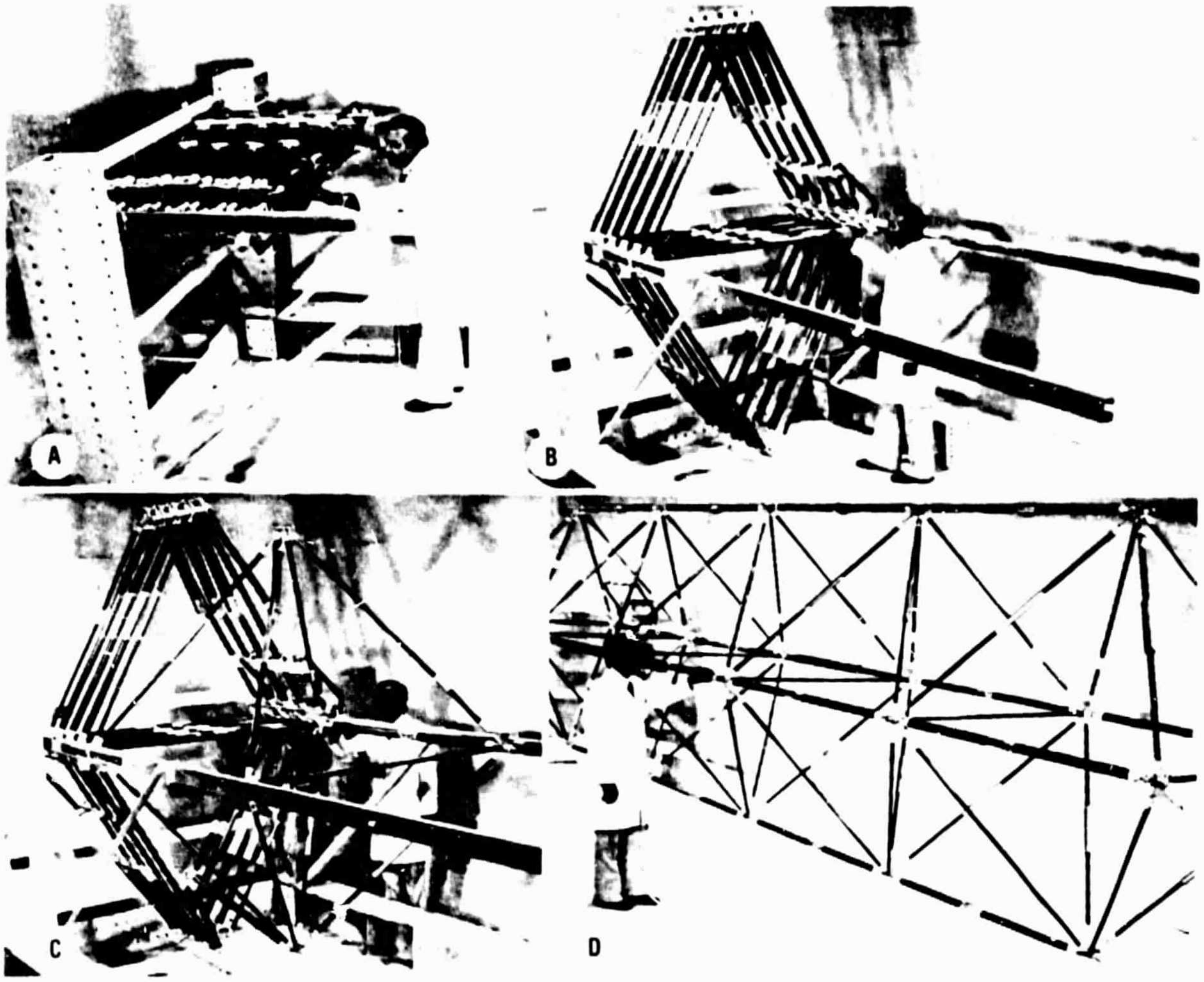
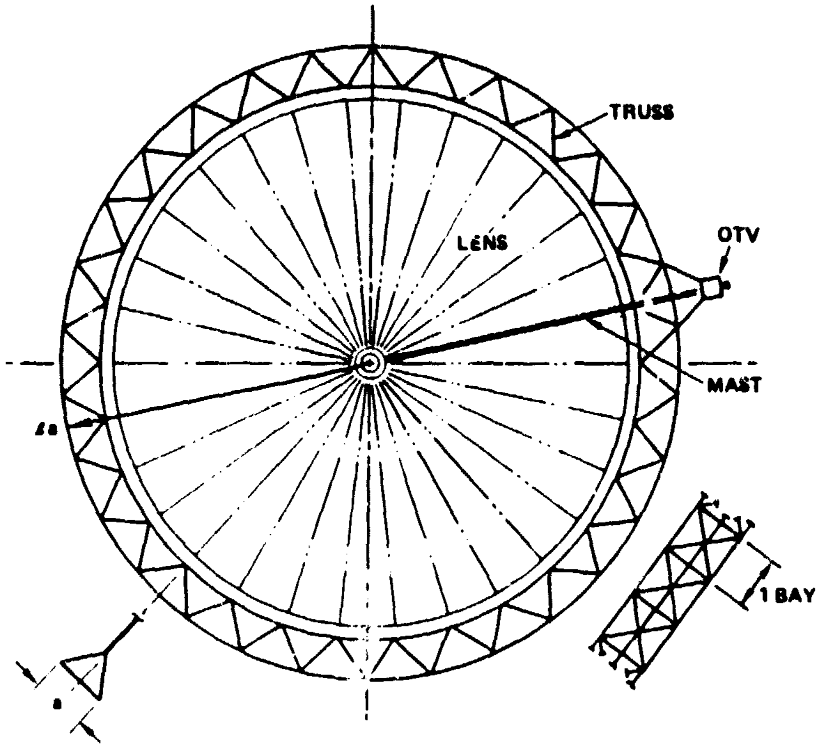


Figure 2-7. GDC tetrahedral truss demonstration.

2.3.1.2 Tetrahedral Truss (Ring). This concept (annular phased array antenna), shown in Figure 2-8, has planar (edge) thrust application. The design flexibility of the basic PETA (parabolic expandable tetrahedral antenna) has been exploited to form a ring structure.

The annular expandable truss supports a lens array. The hub, in this case, is located on the array periphery, and the OTV thrust vector acts on the hub along a radial in the plane of the array. The feed support boom is assumed to be retracted during LEO-to-GEO transfer and, as such, adds only to the hub weight.

The deployment sequence is shown in Figure 2-9.



WEIGHTS, LB

TOTAL PAYLOAD	15,204
STRUCTURE	1,062
NODES (JOINTS	2,990
LENS (ANTENNA)	6,291
HUB (CORE)	4,861
DIAMETER, FEET	396

THE TETRAHEDRAL TRUSS IS ALSO USED TO FORM ANNULAR RING FRAME

Figure 2-8. Tetrahedral truss space based radar.

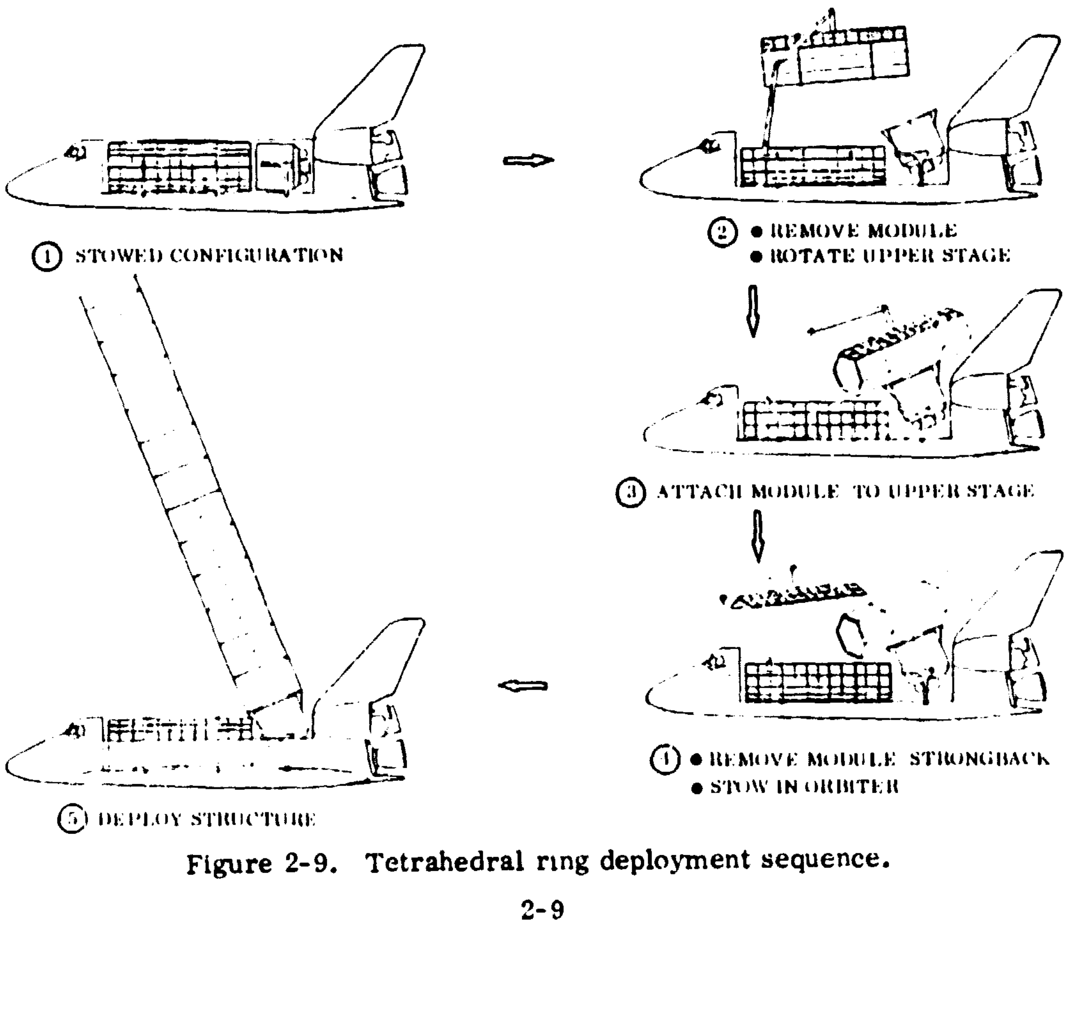


Figure 2-9. Tetrahedral ring deployment sequence.

2.3.2 GEOPLATFORM. One version of the Geoplatform Communication Antenna concept being considered is shown in Figure 2-10.

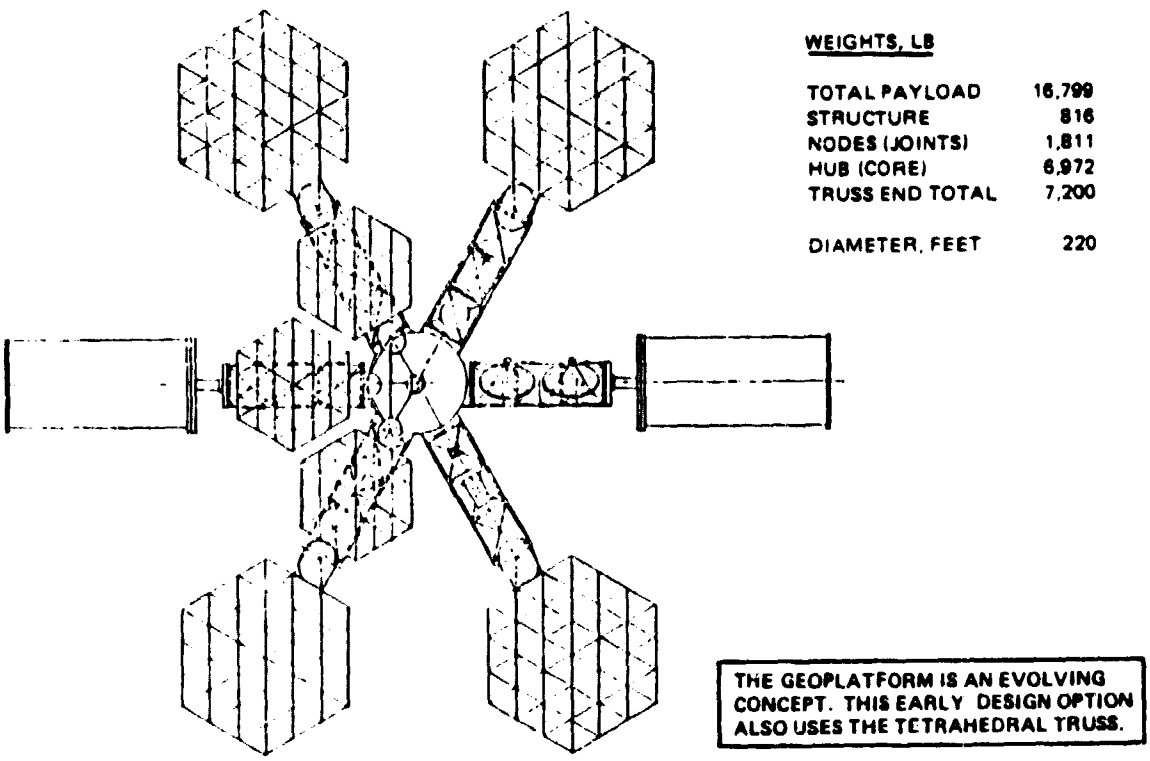


Figure 2-10. Geostationary platform.

The Geoplatform truss arrangement is similar to that of the SBR tetrahedral truss (arm) but it does not include a lens array and associated feed. Individual add-on packages, such as solar arrays, antennas, attitude controllers, expendables, and receiver/transmitter equipment are, as in the case of the SBR, simulated by equivalent masses located at either the truss ends or at the hub. The OTV thrust vector is coaxial with the hub and normal to the plane of the radial trusses.

a. Mission Goals
   1. Maximize efficient use of available frequency spectrum through frequency reuse and other advanced technologies.
   2. Reduce congestion in the geosynchronous orbital arc.
   3. Reduce costs by subsystem sharing and "economy of scale".
   4. Use primarily for communications (commercial, NASA, and DOD) but also offer tenancy and support for experiments, etc.

b. Background. NASA/MSFC Phase A conceptual definition continuing by GDC with COMSAT, coordinated with commercial interests.

c. Concepts

1. Range from very large, docked modules to a group of platforms "flying in formation".
2. Range in weight from 12,500 to 37,000 pounds requiring 25 to 60 feet stowed length.
3. Early experimental platform planned for 1987; operational units by 1992.

2.3.3 POWER ARRAY. Since the SBR is moderately flexible and the GP is relatively stiff, we initially considered solar arrays to evaluate very flexible structures. However, investigation revealed that the current SEPS arrays (Figures 2-11 and 2-12) are designed to be retracted on orbit in case of solar flares and, therefore, are not really required to be transferred in a deployed condition. (For both the SBR and GP, the solar arrays are not deployed until geostationary orbit is achieved.) Advanced (hardened) solar arrays could be designed to be transferred deployed since they may not have to be retracted on orbit. (Rigid array concepts have been evaluated under Contract NAS8-33442 and some structural concepts are similar to the SBR, such that similar results can be expected.) However, in the future, advanced solar arrays (Figure 2-13) will likely be self-powered (Ion or MPD engines) and, therefore, are not likely candidates for chemical propulsion transfer. As a result, no further consideration was given to solar arrays.

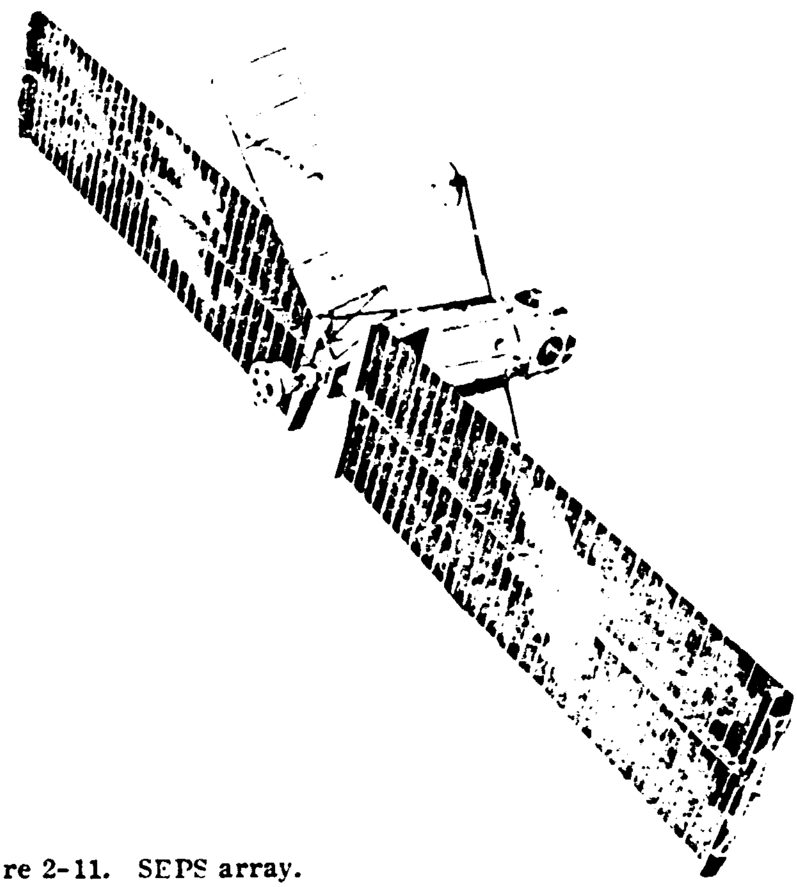


Figure 2-11. SEPS array.

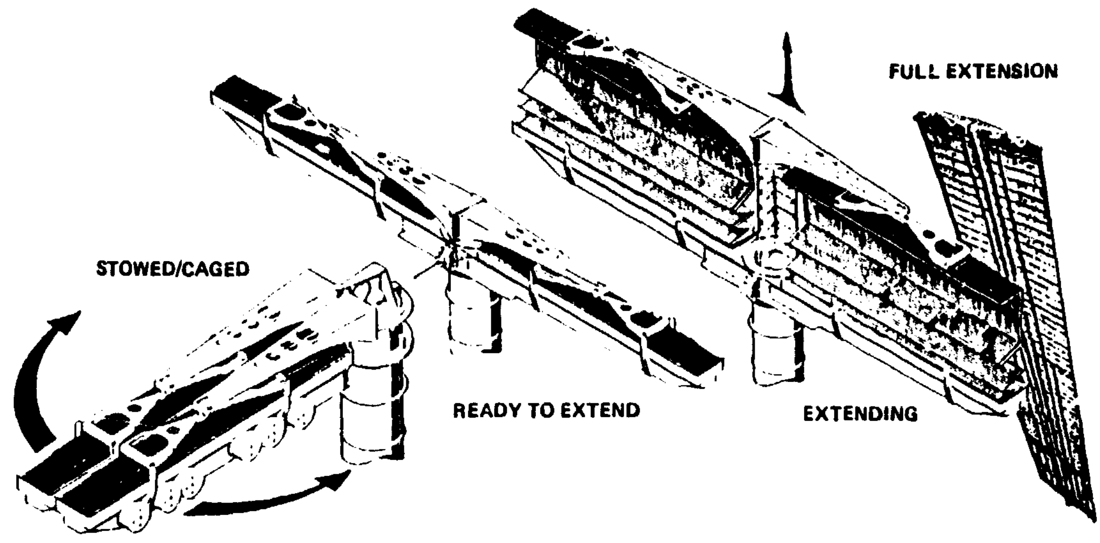


Figure 2-12. SEPS power array deployment.

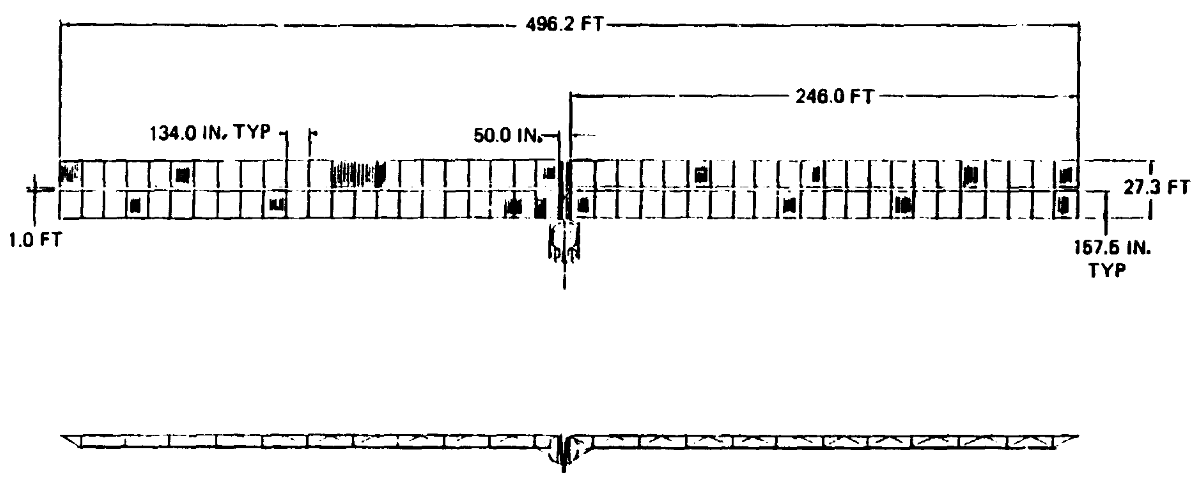


Figure 2-13. Advanced 100 kW power array.

2.3.4 EXTERNAL FORCES AND TORQUES AT LEO. The drag force and torques due to air, solar pressure, and gravity gradient at 200 n. mi. were determined. Using the SBR (arm) concept as an example, the drag (0.72 lb) and torque (13.2 ft-lb) are very small compared to the main engine thrust (>1000 lb), and the external forces vanish during the first burn, even on a 9-burn trajectory.

3

CANDIDATE LOW-THRUST PROPULSION SYSTEM CONCEPTS

Analyses were conducted for expendable vs. reusable, single stage vs. 2-stage, single vs. multiple Shuttle launches, and 65K vs. 100K shuttles. (See Figures 3-1, 3-2, and 3-3.) The most cost-effective option is the single Shuttle-expendable OTV.

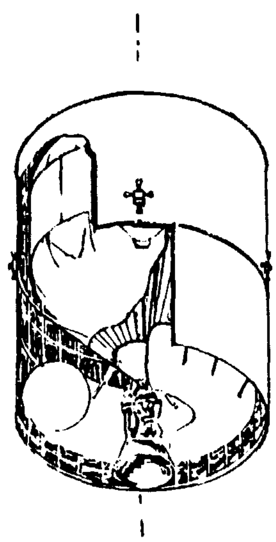


Figure 3-1. Orbit transfer vehicle.

As reported in Section 2, the first 5 years of LSS operations do not require long (60 ft) payloads.

The single (65K) shuttle-expendable OTV option was, therefore, selected for primary study.

3.1 OTV CHARACTERISTICS

To obtain the shortest possible stage to allow maximum payload length, a torus LO_2 tank configuration is superior to all others (conventional suspended tanks, nested tanks). For 40,000 lb propellant at MR = 6, a savings of 9 feet in length is realized.

Although the torus tank itself is heavier, the shorter structural shell and support systems compensate, resulting in nearly equal weight.

The OTV Concept Definition Study (Contract NAS8-33533) has generated detail data on many configurations, permitting determination of OTV parametric relationships as shown in Figure 3-4.

Note that these represent basic weights including all vehicle subsystems. The effects of mission duration, engine thrust, number of engine burns, etc., are separately evaluated.

3.2 PROPULSION CHARACTERISTICS

3.2.1 THRUST TRANSIENT. Engine start and cutoff thrust transient (Figure 3-5) induces oscillation of the LSS, which causes changes in acceleration of the OTV and the propellant mass, both of which are of interest when considering LSS structural loading and OTV propellant acquisition.

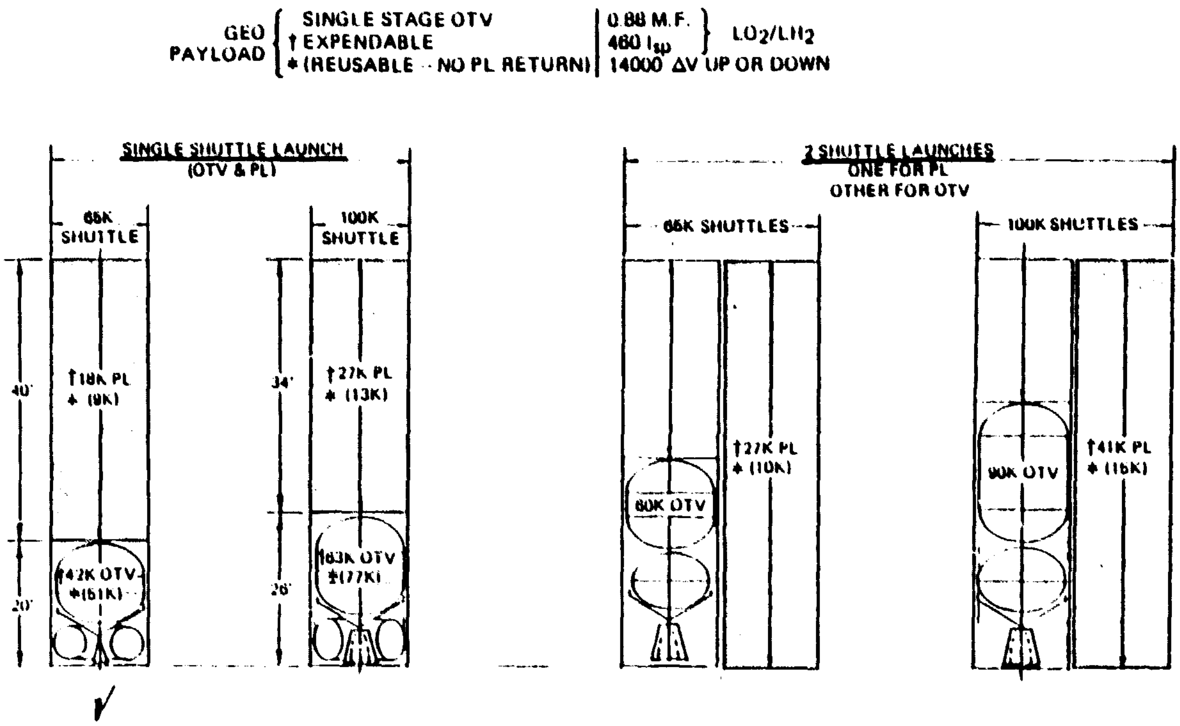
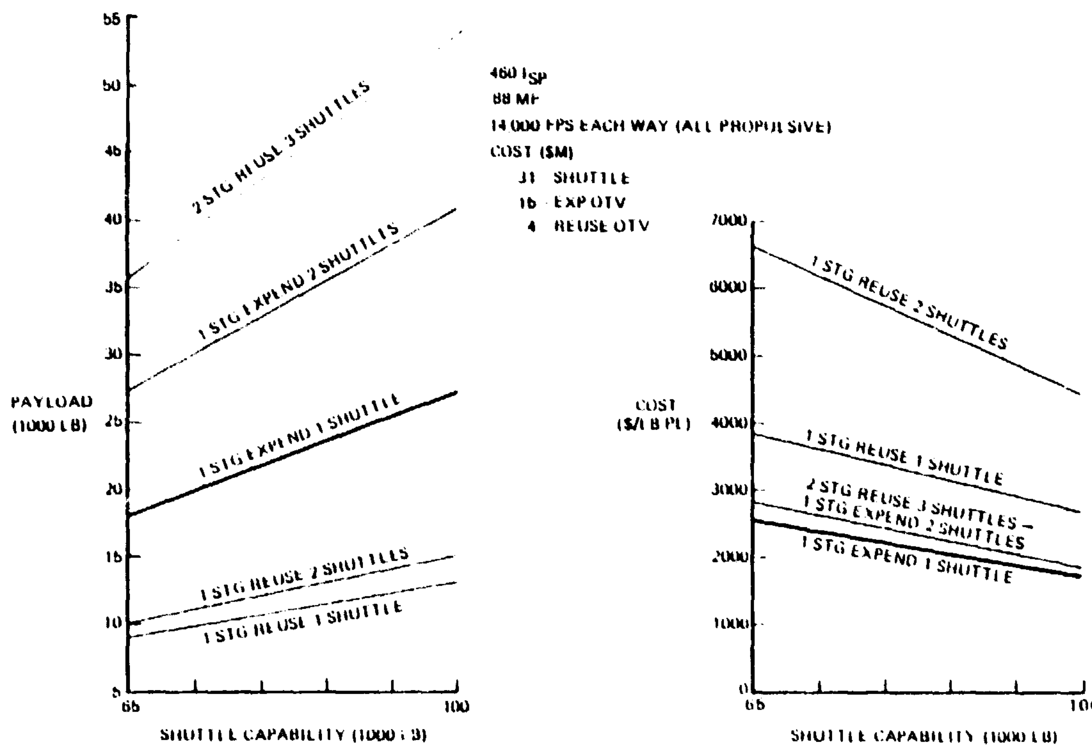
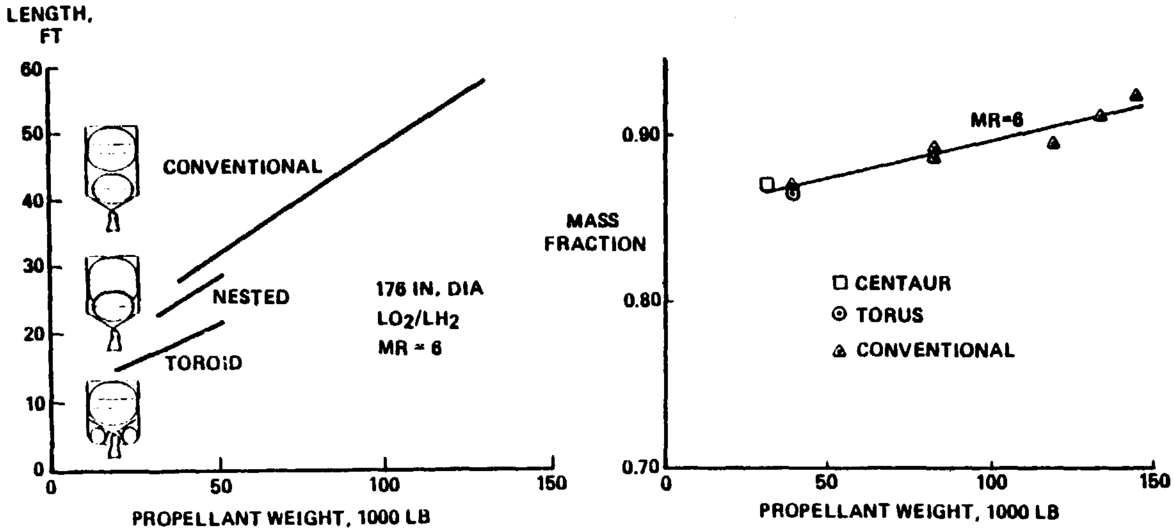


Figure 3-2. Candidate OTV concepts.



SINGLE SHUTTLE/SINGLE STAGE EXPENDABLE OTV IS MOST COST – EFFECTIVE AND LEAST RISK. REQUIRES SHORT OTV – TORUS TANK.

Figure 3-3. OTV options.



TORUS TANK GIVES SHORTEST OTV, WITH LITTLE (<3%) WEIGHT PENALTY – SELECTED FOR BASELINE.

Figure 3-4. OTV length and mass fraction.

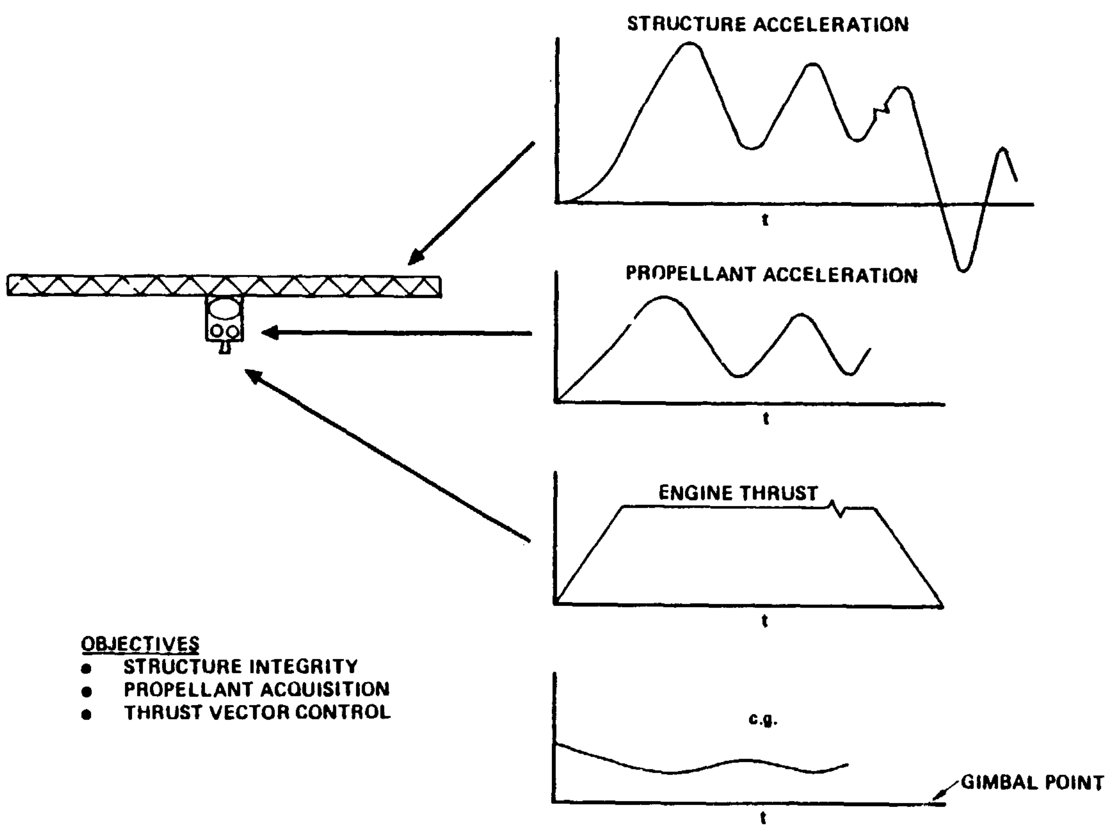


Figure 3-5. Thrust transient interaction.

Figure 3-6 shows results of an investigation of the dynamic response of the OTV (coupled with the payload) as a function of thrust rise time. It can be seen that no negative acceleration occurs.

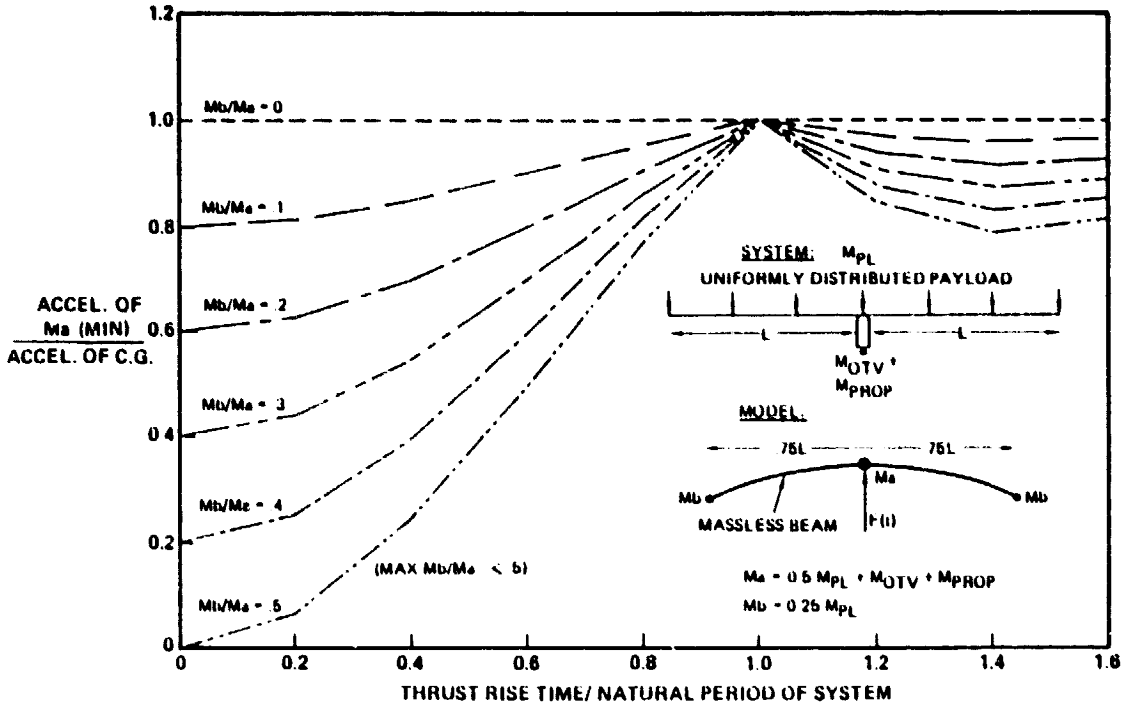


Figure 3-6. Minimum dynamic response.

Similarly, the maximum dynamic acceleration was determined. In general, a dynamic factor of $\leqslant 2$ resulted.

Consideration has been given to stretching out the engine thrust transient to result in factors nearer to 1. Since engine thrust rise times are typically less than 1/2 second and the structures' natural periods are 2 seconds and greater, this would require engine design changes. However, as discussed in Section 4, the effect on the structure is negligible whether the factor is 1 or 2 and, therefore, there is no need to slow down the thrust transient.

3.2.2 DISTRIBUTED THRUST. Application of distributed thrust on the payload structure should ideally result in better load distribution and, therefore, lower weight, and could offer the possibility of a common main propulsion and attitude control system. However, the imposed design complications (plumbing, etc., for a deployable system) and the dynamic characteristics incurred by expected variations in thrust transient phasing are such that this would be difficult to achieve.

Ideally, the static bending moments and the dynamic response would be reduced if the thrust rise and cutoff of each engine were phased exactly together. However, dynamic response could be increased since exact phasing is unlikely with multiple, distributed thrusters. (Even with quite closely related thrusters, e.g., Atlas, Centaur, significant lateral dynamic loads are encountered.)

Figure 3-7 shows the results of an analysis for two thrusters separated by 20% (of the structure diameter). The figure shows that small differences in thrust transient cause significant increase in dynamic factors. Refer to Appendix 12 for details.

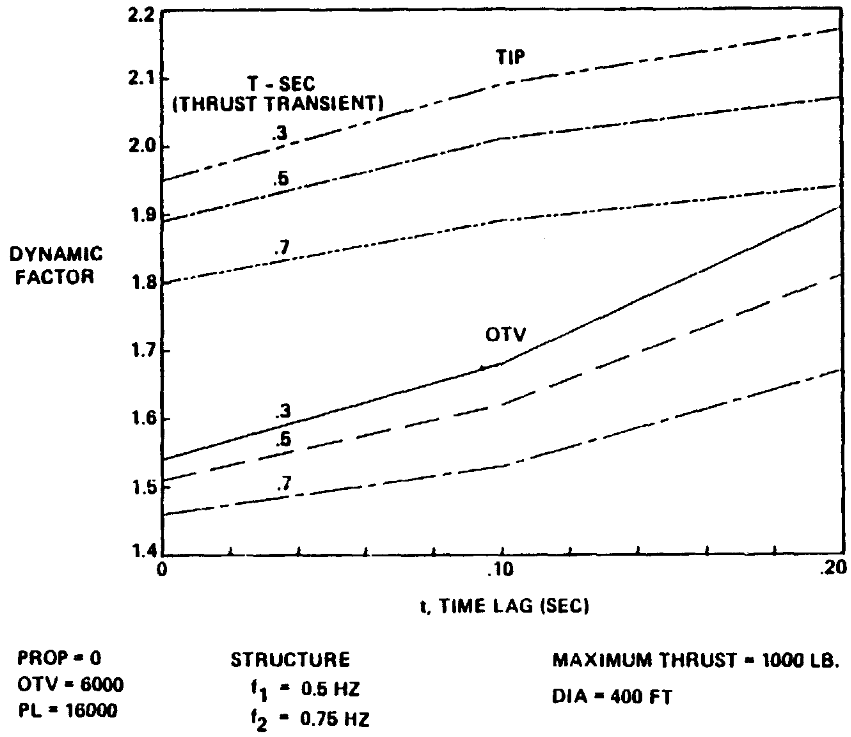


Figure 3-7. Distributed thrust - 2 thrusters ≤ 0.2 D apart.

3.2.3 THRUST VECTOR CONTROL. The OTV will have a thrust vector control system using vehicle rate and attitude to provide commands to gimbal the engine. The control systems also have the capability of shaping the thrust vector commands as a function of time and frequency. The following assumptions were made for this analysis.

a. An autopilot using attitude and rate without filtering is assumed.

b. The lowest two elastic modes for the payload/upper stage combination were calculated by an approximate analytic technique. The frequencies are 0.2 and 0.65 Hz.

c. The control frequency was set at 0.011 Hz.

d. The elastic modes were assumed to have zero damping, this being a worst case. (All damping is provided by the attitude control system.)

Since the elastic modal frequencies are well above the control frequency, coupling is weak and elasticity has little effect on the rigid body response.

The analysis showed that the rigid body and elastic modes are stable when an initial attitude error of 5° was used. The rate traces (Figure 3-8) show that although the elastic modes are excited by the large attitude step, they are damping out. Analysis, therefore, shows that current upper stage control systems are adequate.

The c.g. for the baseline OTV is always forward of the gimbal point due to the attached payload. (After payload insertion, the OTV ACS provides disposal ΔV.)

3.2.4 EXHAUST PLUME INTERACTION. The question of OTV engine exhaust plume impingement on the LSS was analyzed and was determined to present no problem if high expansion ratio nozzles are used. (See Figure 3-9.) For a hydrogen-oxygen engine with an $\epsilon = 400$, the Prandtl/Meyer turning angle for Mach = ∞ is 82.9 degrees. Even with the engine gimbaled 10 degrees, impingement would not occur until a radial distance of 385 feet was reached, assuming a 20-ft long OTV. This exceeds any of the payloads currently being evaluated.

3.2.5 ENGINES. Low thrust engine performance data were obtained from the LeRC low thrust engine studies, from MSFC OTV engine (pumped idle mode) studies, and from Pratt & Whitney for the RL10, IIB, each of which shows a falloff in Isp at lower thrust levels. The performance for either the new low thrust engine or the advanced OTV engine is equivalent, while the RL10, IIB runs about 30 seconds less.

Comparison of low thrust engine characteristics is shown in Figures 3-10 and 3-11, and in Table 3-1 (reference sources are indicated on Figure 3-11).

The factors considered in evaluating fixed thrust vs. throttling (discussed in Section 4) are shown in Tables 3-2 and 3-3.

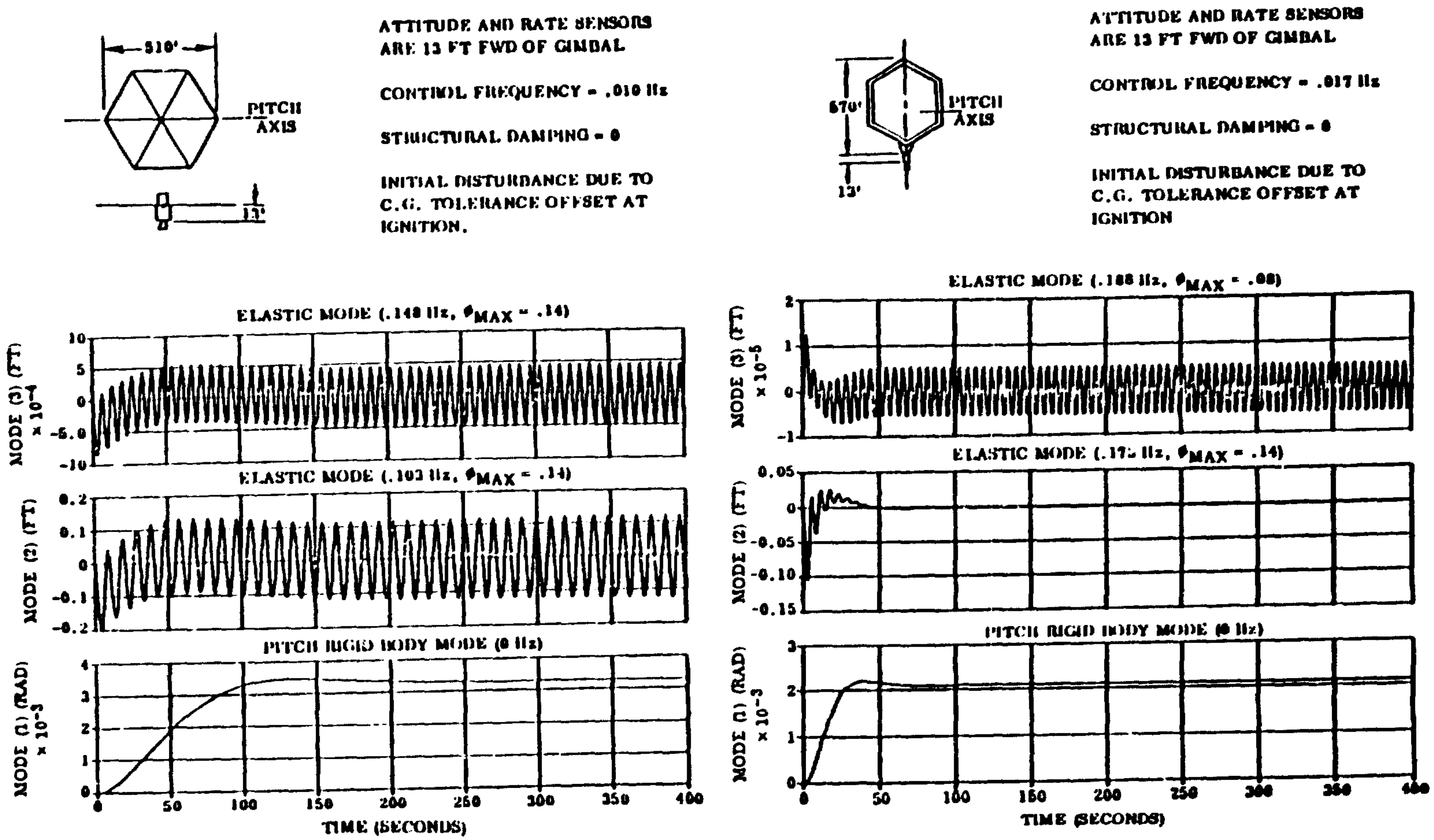


Figure 3-8. LSS dynamic response to thrust vector control system.

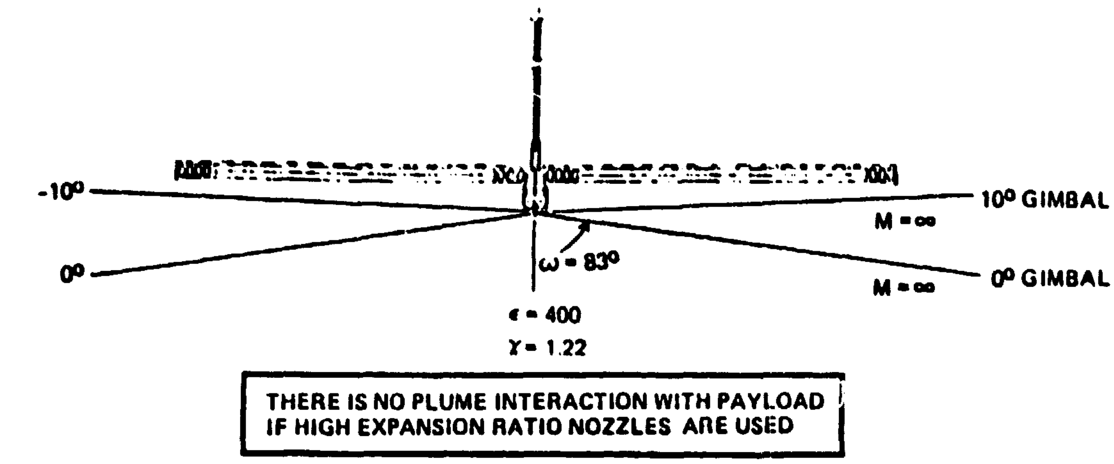
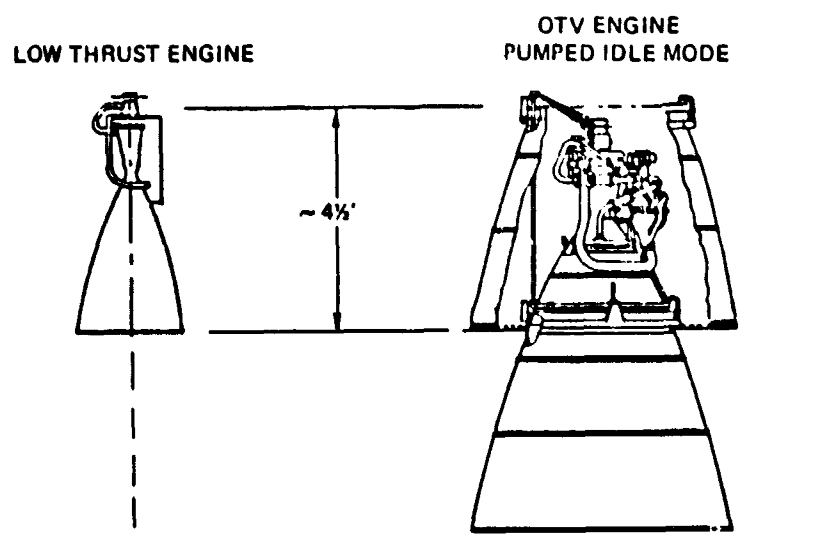


Figure 3-9. Exhaust plume interaction.



	Low thrust engine	OTV engine, pumped idle mode		
	NEW	NEW	NEW + KIT*	RL10,II B
THRUST, LB	1500	1500	1500	3500
I_{SP}, SEC	455	455	470	435

*CHAMBER/NOZZLE (SMALLER THROAT, COUNTERFLOW NOZZLE)

Figure 3-10. Engine options.

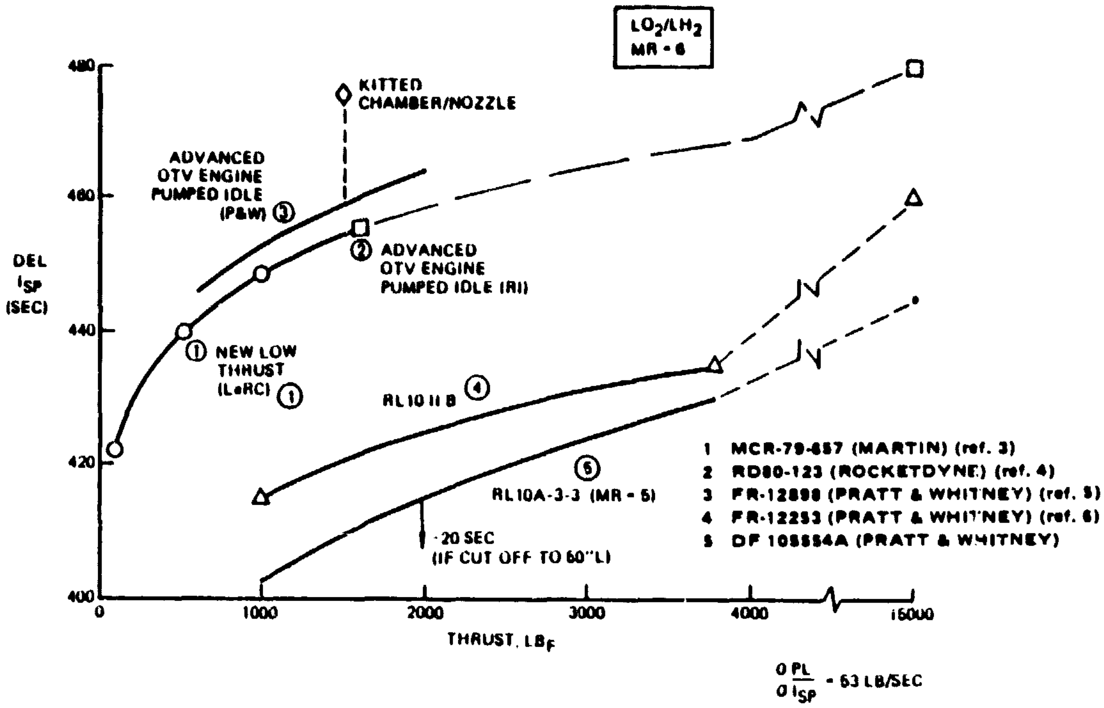


Figure 3-11. Low thrust engine performance.

Table 3-1. Low thrust engine technology.

	NEW LOW THRUST	PUMPED IDLE (OTV ENGINE)
TECHNOLOGY — CONCERNS	— SMALL PUMPS, COOLING, AND PERFORMANCE	— PERFORMANCE AND STABILITY AT 10% THRUST

Table 3-2. Fixed thrust vs. throttling.

	FIXED LOW THRUST (VARIABLE T/W)	THROTTLING (FIXED T/W)
DESIGN	— SIMPLER	— MORE COMPLEX
PAYLOAD (LSS SIZE)	— MORE	— LESS (MORE SENSITIVE)
NUMBER OF BURNS	— MORE (9)*	— FEWER (2-4)
MISSION DURATION	— 3-1/4 DAYS*	— 2-1/2 DAYS

* NO CONCERN FOR PAYLOADS, OTV, OR OPERATIONS

- MULTIPLE BURNS ARE SOA (e.g., 7 BURN CENTAUR)
- INFLUENCE OF ENGINE THRUST LEVEL OR NUMBER OF BURNS HAS MINIMAL EFFECT ON OTV TANK PRESSURES OR VAPOR RESIDUALS
- TDRSS WILL PROVIDE COMMUNICATION/TRACKING
- ELECTRONICS BEING DESIGNED FOR 5 YR IN 5600-N. MI. ORBIT

Table 3-3. Mission time (0.05 g max).

	TWO-BURN CONSTANT ACCELERATION	NINE-BURN CONSTANT THRUST
LAUNCH/CHECKOUT IN LEO	40 HR	40 HR
ENGINE BURN TIME	2.5 HR	5 HR
LEO-GEO TRANSFER	8 HR	24 HR
DISPOSAL ORBIT PLACEMENT	12 HR	12 HR
	62.5 HR	81 HR
TOTAL	2-1/2 DAYS	3-1/4 DAYS

4

PERFORMANCE ANALYSIS

A computerized analytical model was developed to synthesize and optimize the operational and hardware parameters of three different large space structural systems and their OTVs.

Five main considerations were evaluated to determine the characteristics of greatest influence. (See Figure 4-1.)

a. The large space structure weight/size vs. static load factor.

b. The large space structure load amplification factor.

c. The low thrust trajectory ΔV required vs. T/W and number of burns.

d. The OTV performance (function of engine, thrust, number of burns).

e. The packaging in the Shuttle.

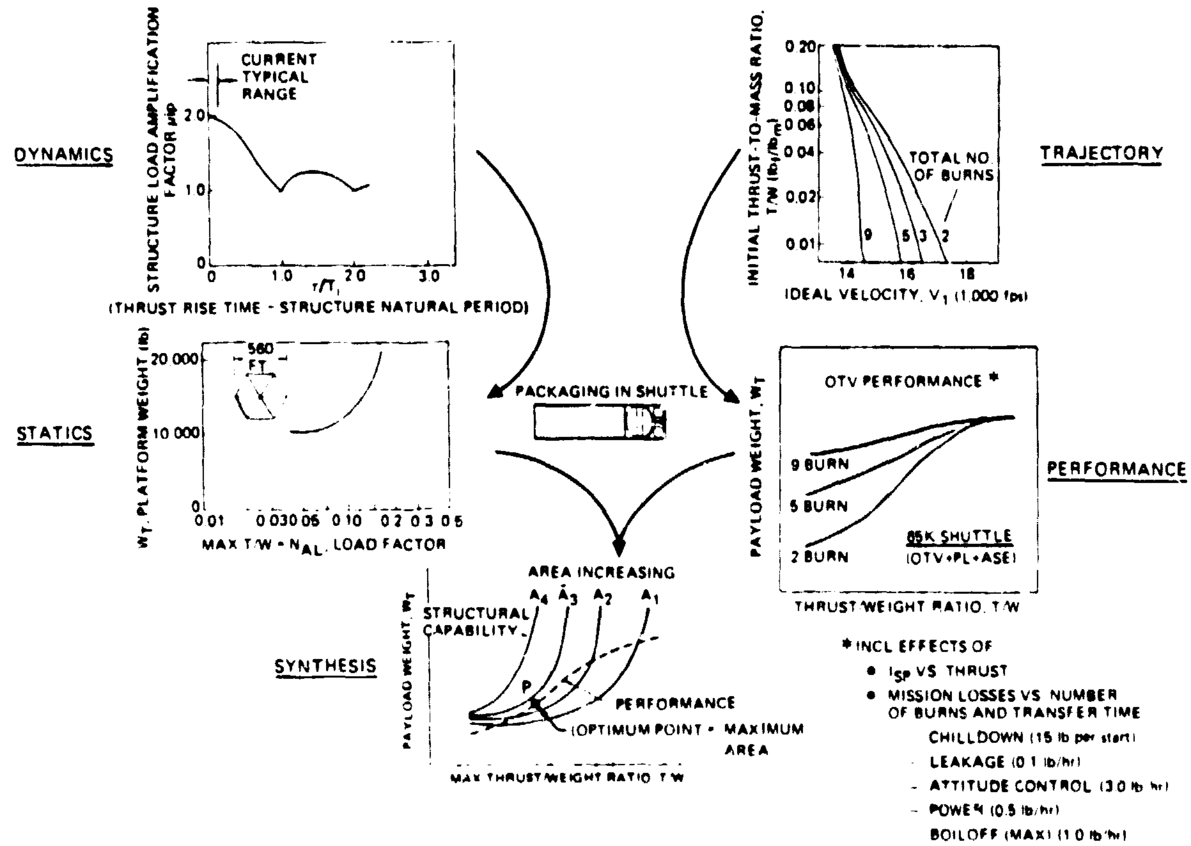


Figure 4-1. Performance analysis.

4.1 COMPUTER SYNTHESIS/OPTIMIZATION

The OPTOTV computer program (Figure 4-2) is both a synthesis and optimization program for parametric and trade studies of LSS and OTV configurations operating out of the Shuttle. The program has the following features.

It accepts LSS truss structure material properties, and minimum member size and gage limitations. For purposes of this analysis, graphite composite having an $E = 40 \times 10^6$ psi and an $F_{cy} = 37,000$ psi, and aluminum (6061-T6) having an $E = 10^7$ psi and $F_{cy} = 35,000$ psi are used. Minimum primary tube diameter and thickness are 2 and 0.05 inches, respectively.

The program accounts for the Shuttle payload weight and volume constraints as well as the configuration of the OTV (i.e., mass fraction and length vs. propellant weight) and its propulsion system Isp vs. thrust characteristics.

The input also includes factors for weight of joints, the LSS hub weight, dynamic amplification factors, and number of burns.

INPUT

- MATERIAL PROPERTIES
- MINIMUM INITIAL T/W = .001
- MINIMUM SIZE AND GAGE LIMITATIONS
- SHUTTLE PAYLOAD AND VOLUME CONSTRAINTS
- OTV PROPULSION SYSTEM AND CONFIGURATION
- NUMBER OF BURNS
- FACTORS: - WEIGHT OF JOINTS
  - HUB WEIGHT - ARRAY WEIGHT
  - THRUST CUTOFF AMPLIFICATION

OUTPUT

- LSS - DEPLOYED AND STOWED STAGE GEOMETRIES
  - STRUCTURAL AND MASS PROPERTIES
- OTV - THRUST LEVEL - MASS PROPERTIES - ΔV REQUIREMENTS
  - SIZE - PAYLOAD CAPABILITY - STAGE WEIGHTS

PAYLOAD WEIGHT AND OTV PAYLOAD CAPABILITY CHECK

PAYLOAD, OTV AND SHUTTLE, WEIGHT AND VOLUME FIT CHECK

OPTIMUM PAYLOAD AND OTV PARAMETERS

Figure 4-2. Computer program overview.

Through an iterative computational process the program computes stowed and deployed sizes as well as structural and mass properties. It checks critical stresses including Euler column buckling of truss member tubes and also radar-array-membrane stresses. If stresses are unacceptable, the tube diameters are first iteratively increased up to the point at which volume limitation constraints are encountered. After this, the tube wall gages are increased as necessary up to the point at which weight limitation constraints are encountered. It then computes OTV length, mass, and performance parameters. To perform these analyses, it must compute ΔV impulse velocity requirements to achieve orbital transfer for the selected input number of burns and initial acceleration.

Fit checks are performed to determine, for a given T/W and structure size, if the payload and volume limitations of the Shuttle are met and if the OTV payload capability matches the actual payload weight. The structure size is then systematically increased until either volume and/or weight limitations are encountered, at which point the maximum LSS size is assumed to have been achieved. The T/W is next increased and the above process is repeated to generate data for LSS size vs. T/W. For each T/W all characterizing parameters of the LSS and OTV are computed and printed out along with a factor for the fraction of the total Shuttle cargo bay length utilized. In all cases the full payload capabilities of the Shuttle are used.

Appendices 1 through 7 define all elements of the OPTOTV computer program.

4.2 PAYLOAD CONFIGURATIONS

The selected payloads, defined in Section 2, are summarized as follows:

a. Space Based Radar - Tetrahedral Truss Arms (SBR-A). Six radial expandable truss structures support an active lens array having a hexagonal flat pattern. The hub to which these truss structures are attached also mounts an antenna-feed support boom. Packages such as solar arrays, attitude controllers, expendables, and receiver/transmitter equipment are located at either the truss ends or at the hub. The OTV is also adapted to the hub and its propulsion thrust vector is normal to the plane of the lens array.

b. Space Based Radar - Tetrahedral Truss Ring (SBR-R). The annular expandable truss supports a lens array. The hub, in this case, is located on the array periphery, and the OTV thrust vector acts on the hub along a radial in the plane of the array. The feed support boom is assumed to be retracted during LEO-to-GEO transfer and, as such, adds only to the hub weight.

c. Geoplatform. The radial truss arrangement is similar to that of the SBR-A but it does not include a lens array and associated feed. Individual add-on packages, such as solar arrays, antennas, attitude controllers, expendables, and receiver/transmitter equipment are, as in the case of the SBR-A, simulated by equivalent masses located at either the truss ends or at the hub. The OTV thrust vector is coaxial with the hub and normal to the plane of the radial trusses.

4.3 PAYLOAD-OTV-SHUTTLE LENGTH FIT

Figure 4-3 shows the configuration of the stowed payload envelope and the OTV to which this payload mates. As shown in the figure, the allowable mated length is 59.1 ft for 30° launch elevation with respect to the Shuttle and 55.9 ft for 75° elevation. For purposes of this study, a mated length (i.e., usable length of cargo bay) is taken as 57 ft.

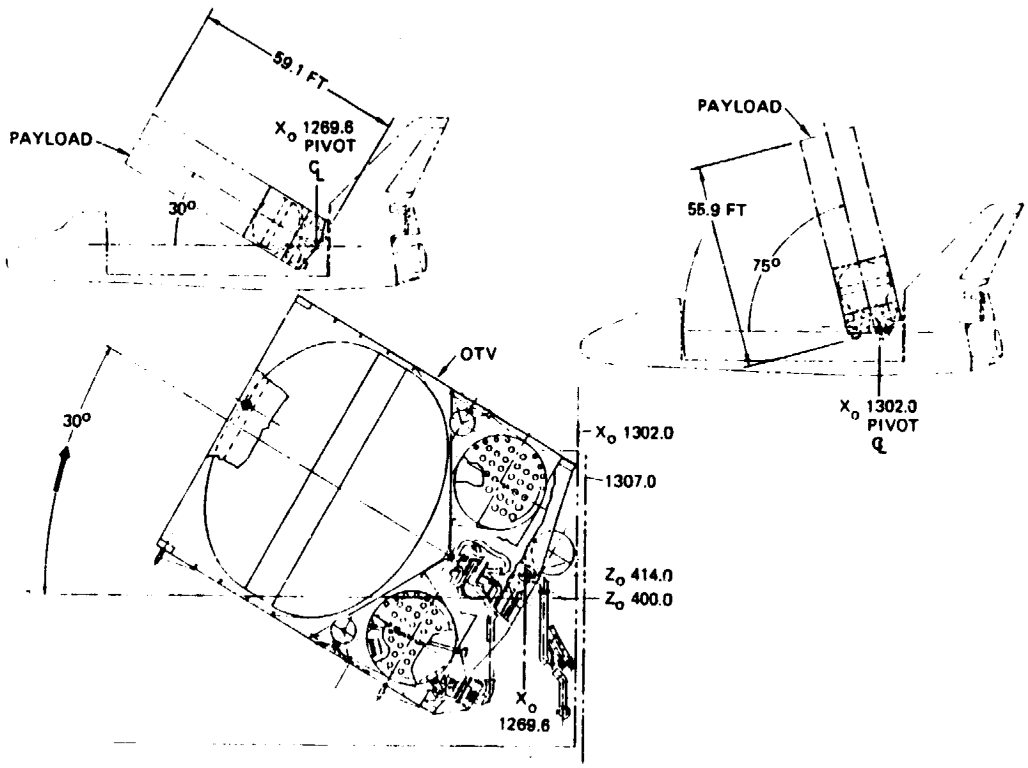


Figure 4-3. Payload-OTV-Shuttle length fit.

4.4 OTV CHARACTERISTICS.

The OTV is an LO_2/LH_2 vehicle having a toroidal LO_2 tank and a conventional LH_2 tank. For purposes of this study the OTV outside shell diameter is held constant at 176 inches while its length is varied for stage sizing.

4.4.1 VELOCITY REQUIREMENTS VS. INITIAL THRUST-TO-WEIGHT. Figure 4-4 shows velocity requirements for LEO-to-GEO transfer vs. initial thrust-to-weight (TP) for N = 9, 5, and 2 total burns based on constant thrust engine performance and for N = 2 based on constant thrust-to-weight (TW) engine performance. The trajectory methods originally developed by GDC for the Air Force in the "On-Orbit Assembly Study", reference 2, have been used in this study. Recent work by Martin has verified our original work. The algorithm describing the first set of these curves is contained in Appendix 1 under V, V1, and V2. Similar data are used for the constant TW curve. This algorithm defines a linear piecewise approximation of the curves in Figure 4-4 where V1, V2, and T3 and T4 (per listing in Appendix 3) are, respectively, the velocity and initial thrust-to-weight ranges in the algorithm. For constant thrust engine performance the final thrust-to-weight (TW) is related to initial thrust-to-weight in the TP algorithm.

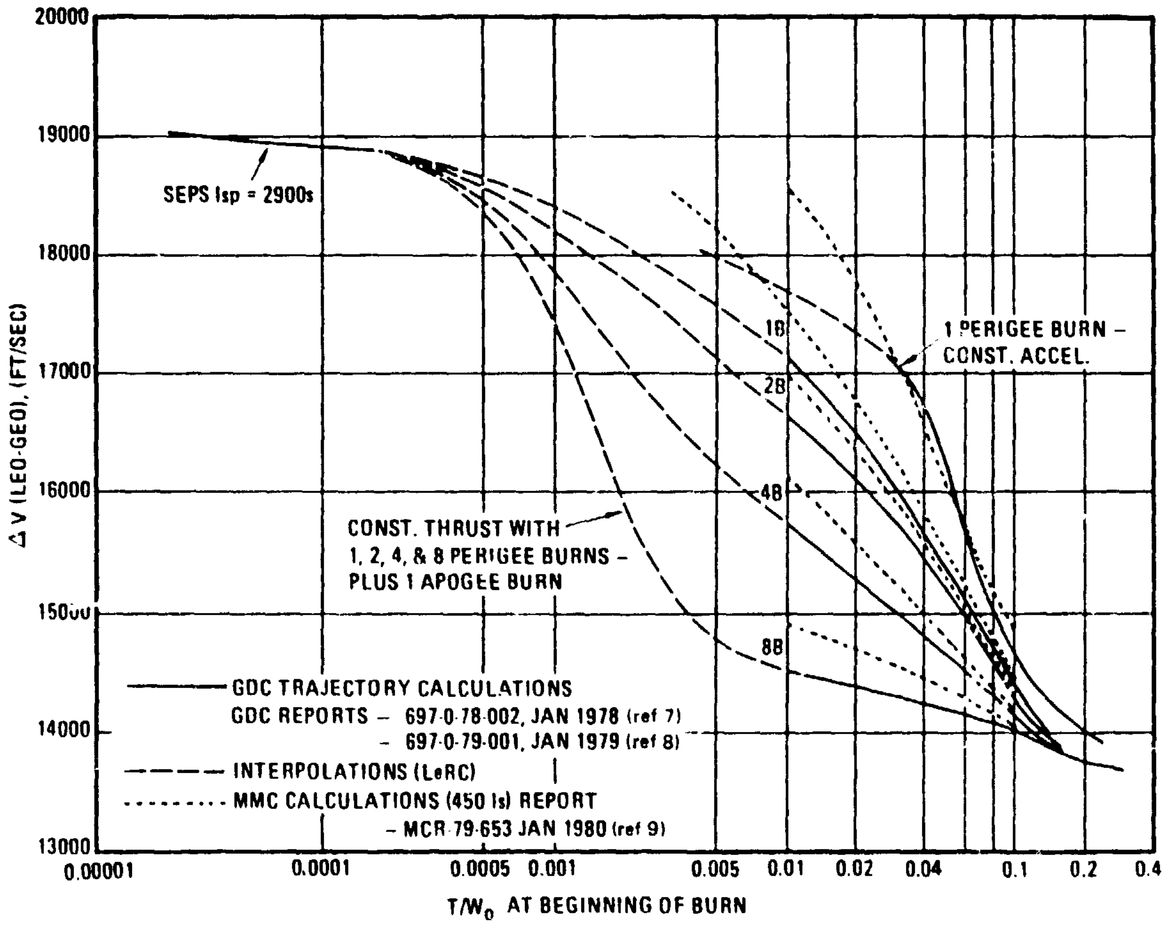


Figure 4-4. Low thrust ΔV requirements - LEO to GEO.

4.4.2 Isp VS. THRUST. The Isp (IS) vs. thrust (TT) used in this study is shown in Figure 4-5 and the algorithm for IS, based on curve fitting, is given in Appendix 1.

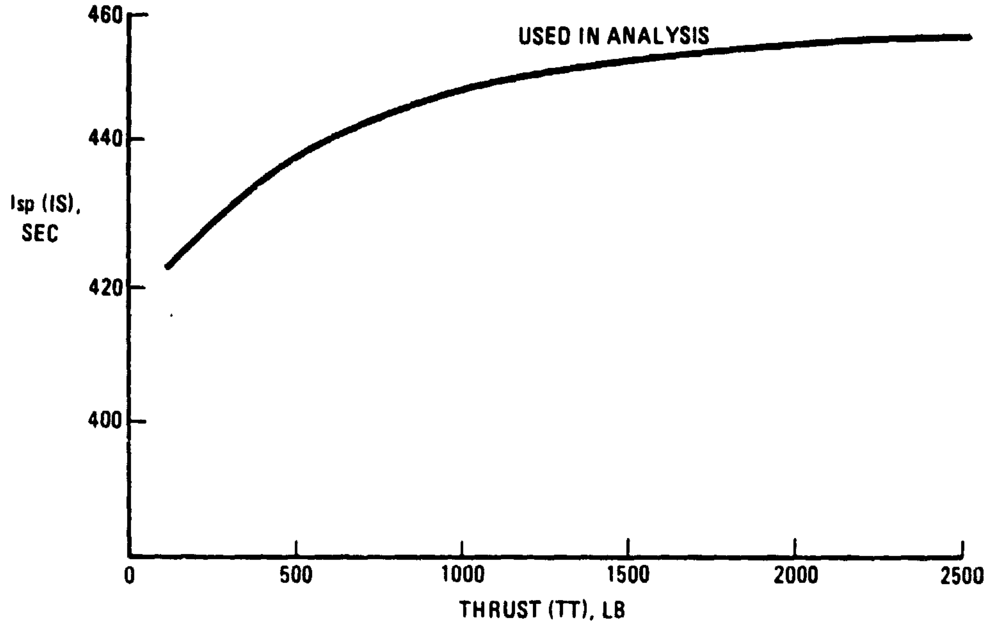


Figure 4-5. Isp vs. thrust (low thrust engine performance).

4.4.3 OTV LENGTH VS. PROPELLANT WEIGHT. The OTV length (LP) vs. propellant weight (PW) for the toroidal configuration used in this study is shown in Figure 4-6 and the describing algorithm for LP is in Appendix 1.

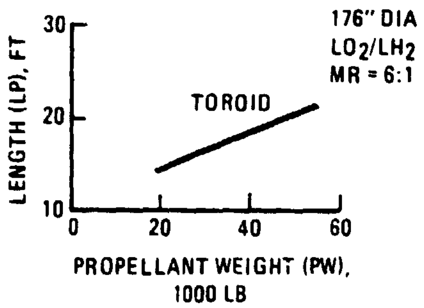


Figure 4-6. OTV length vs. propellant weight.

4.4.4 MASS FRACTION VS. PROPELLANT WEIGHT. The OTV mass fraction (MU) vs. propellant weight for the toroidal configuration used in this study is shown in Figure 4-7, and the describing algorithm for MU is in Appendix 1.

4.4.5 MISSION LOSSES. Table 4-1 summarizes mission losses (PL) analytically defined in Appendix 1 as a function of propellant weight loss per engine start (KS), per hour due to leakage, boiloff, and attitude control (KT), and for onboard power generation (PP). The latter is a function of the weight per hour for electric power up to the first 12 hours (KP), and after 12 hours (KQ). See Appendix 1 for definitions.

KS = 15 lb/start
KT = 4.1 lb/hr
KP = 21 lb/hr
KQ = 0.5 lb/hr

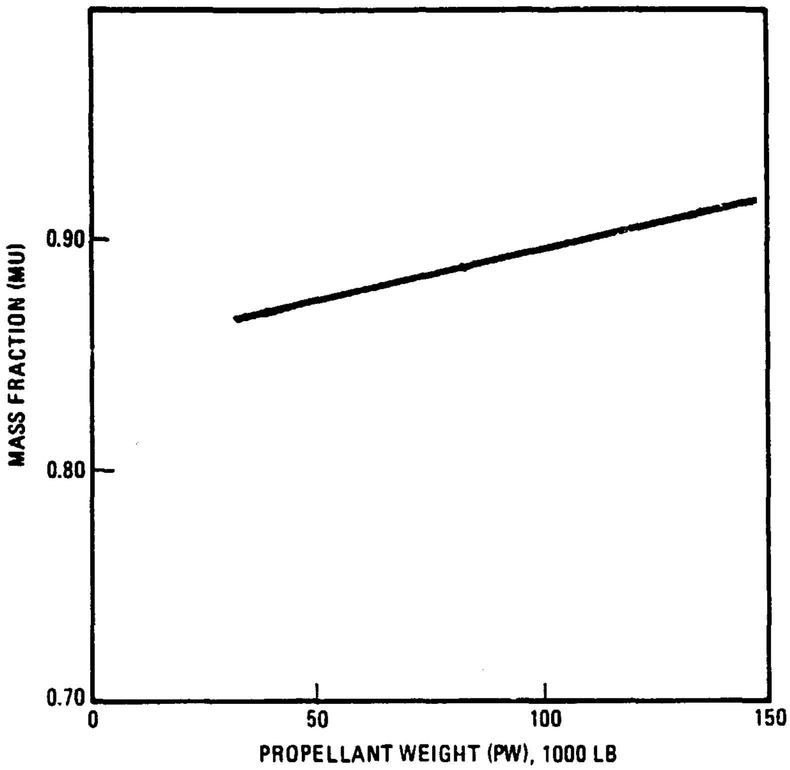


Figure 4-7. OTV mass fraction vs. propellant weight.

Table 4-1. Mission dependent losses.

- LOSS RATE

CHILLDOWN	–	15 LB (MAX) PER START (ZERO IF TANK HEAD IDLE)
LEAKAGE	–	0.1 LB PER HOUR
BOILOFF	–	1.0 LB PER HOUR
ATTITUDE CONTROL	–	3.0 LB PER HOUR
POWER	–	21 LB PER HOUR UP TO 12 HR (BATTERIES) 0.5 LB PER HOUR AFTER 12 HR (FUEL CELL)

- MISSION DURATION = (COAST TIME) + (BURN TIME)

NUMBER OF BURNS (INCL 1 APOGEE)	COAST TIME (HR)
2	5
5	10
9	25

$$\text{CONSTANT THRUST BURN TIME (HR)} = \frac{\text{PROPELLANT WEIGHT (LBM)}}{\text{THRUST (LBF)} \times 3600} \cdot I_{SP}$$

$$\text{CONSTANT ACCELERATION BURN TIME (HR)} = \frac{\Delta V \text{ (FT/SEC)}}{(T/W)\ (32.2)\ (3600)}$$

4.4.6 SUMMARY OF OTV PARAMETERS. Appendix 6 lists under GENERAL the OTV input and output parameters handled in the OPTOTV computer program. Analytical definitions for these parameters are given in Appendix 1. Note that the OTV payload capability (WY) has one of two definitions depending on (menu-selected) number of Shuttles used in a mission.

The OTV performance parameters described above are an integral part of the OPTOTV computer program and, as such, are iteratively evaluated in conjunction with iterative evaluations of payload-describing parameters.

4.5 PAYLOAD CHARACTERISTICS

General and peculiar payload characteristics are described in this subsection for the three different generic LSS systems chosen for purposes of this study.

4.5.1 SPACE BASED RADAR - TETRAHEDRAL TRUSS ARM (SBR-A). The SBR-A consists of six deployable truss frame structures that mount a lens array. The hub to which the trusses are attached also mounts a deployable feed assembly and an OTV adapter structure. The OTV thrust acts normal to the plane of the deployed trusses.

Attachments on the ends of the SBR-A trusses such as solar arrays, attitude controllers, and electronic equipment are taken as lumped weights (WT) as are all weights associated with the hub (WH). Orbital transfer is assumed to take place with the WT and WH deployable structures in stowed states. Thus, a solar array on the end of a truss and a feed support boom on the hub would be in their retracted states during orbital transfer.

The stowed geometry of the truss structures is shown in Figure 4-8. Note that each bay of a truss folds into a volume C_1, C_2, a (or C1, C2, A in computer symbols).

The OPTOTV input and output SBR-A parameters are listed in Appendix 6 under GENERAL, Payloads and SBR-A Peculiar. Algorithms and definitions for these parameters are given in Appendix 1. The input parameters of particular importance are ZH (hub weight fraction) and FB (joint weight factor in truss), which are products, respectively, of system and structural design requirements. Input data under GENERAL, Shuttle, such as LQ and RS (available Shuttle cargo bay length and radius), also have an important influence on the SBR-A payload sizing.

The SBR-A Peculiar, dynamics output in Appendix 6 is primarily directed at computing $K\phi$ (the worst case thrust amplification factor). The dynamics routine in OPTOTV is identified in Appendix 7, the OPTOTV computer program flow diagram. This routine is only applicable to the SBR-A. Dynamics analyses are not programmed for the geoplatform and SBR-R.

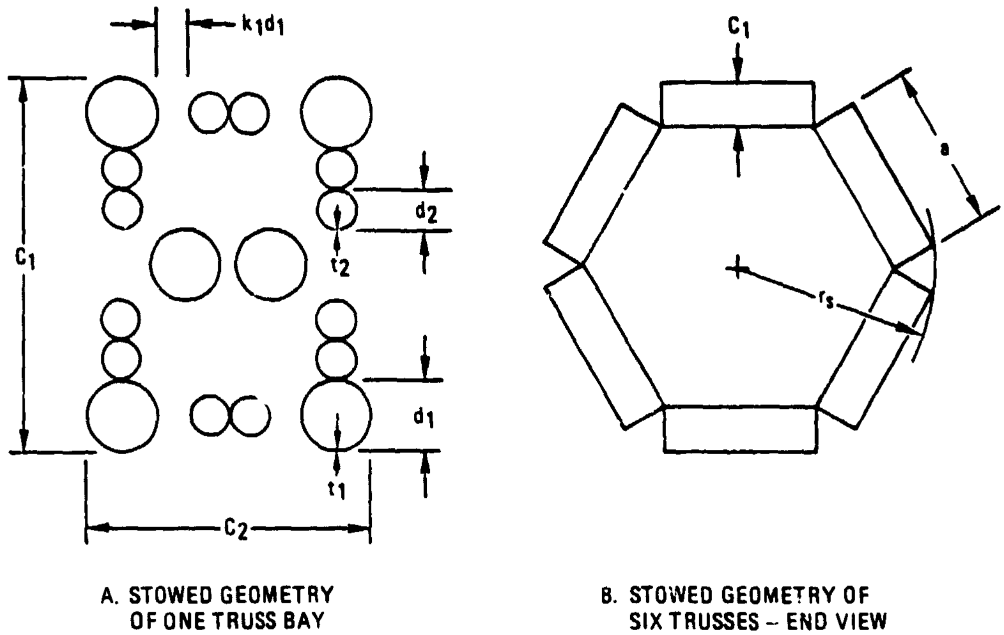


Figure 4-8. SBR-A stowed geometries of bay and trusses.

4.5.2 SPACE BASED RADAR - TETRAHEDRAL TRUSS RING (SBR-R). The tetrahedral ring structure has a triangular cross section (rather than a diamond cross section as in the cases of the SBR-A and geoplatform). The stowed geometry of the SBR-R is shown in Figure 4-9.

Unlike the SBR-A and geoplatform, the SBR-R is not mounted on the OTV while stowed for launch in the Shuttle cargo bay. This is necessary because the length of the stowed package, a, is large compared to the stowed package diameter, and the thrust vector must finally be in the place of the deployed ring structure. It will, therefore, be necessary to perform an on orbit mating or positioning of the SBR-R on the OTV before SBR-R deployment takes place. The remote manipulator system (RMS) may be needed for this assembly operation and, because of this need, the allowable radius of the payload R_S (or RS) is smaller than that used for the SBR-A and geoplatform.

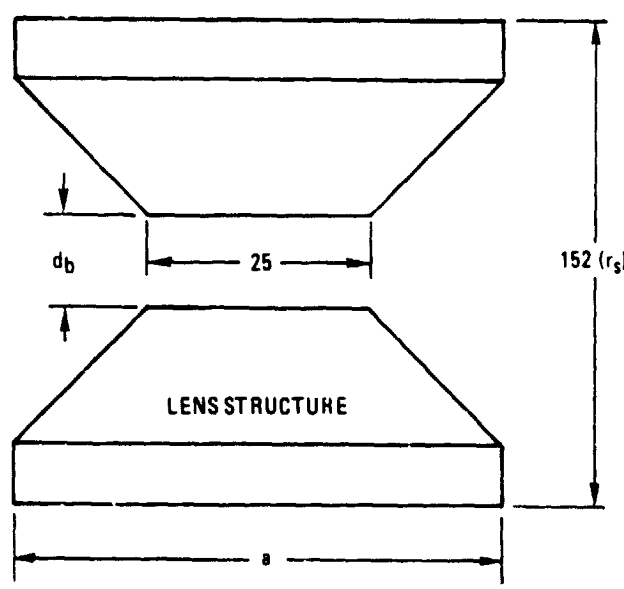


Figure 4-9. Stowed geometry of SBR-R.

Describing input and output OPTOTV parameters for the SBR-R are listed in Appendix 6 under GENERAL, Payloads and SBR-R Peculiar. Definitions and algorithms for applicable GENERAL symbols are given in Appendix 1 and for SBR-R Peculiar symbols in Appendix 2. Note that, in Appendix 2, in addition to new SBR-R peculiar symbols, some of the symbols used in the SBR-A and geoplatform analyses are redefined.

4.5.3 GEOPLATFORM. The geoplatform configuration consists of six radial trusses that support antennas, solar panels, and other equipment, similar to diamond cross section construction of the SBR-A. A lens array is not used in the geoplatform and its hub weights consist only of platform equipment packages. During orbital transfer, thrust-to-weight-critical packages such as solar panels and unfurled antennas are in their stowed positions.

Because of the relatively large weights of the onboard equipment, the size of the geoplatform structures tends to be significantly smaller than that of the SBR-A or SBR-B.

Describing input and output OPTOTV parameters for the geoplatform are listed in Appendix 6 under GENERAL, Payloads and Geoplatform Peculiar. Definitions and algorithms for symbols are given in Appendix 1.

4.6 SHUTTLE CHARACTERISTICS

As indicated in Appendix 6 under GENERAL, Shuttle, the only Shuttle input parameters to the OPTOTV computer program are its cargo bay length (LQ), radius (RS), and payload capability (WS). In selecting values for these parameters, allowances are made for part of the actual Shuttle capacity being used for auxiliary equipment such as the RMS and for related crew support activities.

4.7 OPTOTV COMPUTER PROGRAM

The OPTOTV computer program is both a synthesis and optimization program for parametric and trade studies of LSS and OTV configurations operating out of the Shuttle. The program is described in Section 4.1 and is further defined in this subsection.

Appendices 1 and 2 are alphabetical lists of computer and analytical symbols as well as algorithms and definitions for these symbols. Appendix 1 covers the SBR-A and geoplatform analyses, while Appendix 2 covers new terms and re-definitions of terms in Appendix 1 used in the SBR-R analysis.

Appendix 3 is a combined summary of the literal definitions of computer symbols in Appendices 1 and 2, as well as all iteration and input-output format control symbols.

Appendices 4 and 5 are the OPTOTV computer program listing (written in TRS-80 Disk Basic) and cross-reference listing of lines in which different symbols are used and which are referenced by other program lines. (This reference listing is generated by a Microsoft-Apparat NEW DOS utility program.)

Appendix 6 is a summary of the OPTOTV computer program input-output parameter categories. It indicates the menu of program analysis options which can be selected, as well as the computer symbols for input-output parameters according to the indicated GENERAL and Geoplatform, SBR-A, and SBR-R peculiar categories.

Appendix 7 shows the OPTOTV computer program flow diagram. Computer symbols are used in this diagram.

4.7.1 MISSIONS. Program options in Appendix 6 outline the different missions which are analyzed in this study (per ZZ = 0, 1, 2, and ZO = 1 menu selections). ZZ = 0 (1 payload, 1 OTV, 1 Shuttle) indicates that one payload and OTV assembly is delivered to LEO by one Shuttle flight. ZZ = 1 indicates that the entire Shuttle cargo bay is used to deliver the payload to LEO, and ZZ = 2 indicates that separate Shuttle flights are used for the payload and OTV.

Analyses are generally performed for N = 9, 5, and 2 burns, based on constant thrust engine performance. ; owever, by selecting ZO = 1, the SBR analysis is run on the basis of constant TW (irust-to-weight) and N = 2.

The detailed OPTOTV computer program flow diagram is shown in Appendix 7.

The OPTOTV program can be used to determine a single TW value at which the maximum payload size is achieved. This capability is, however, not used at this time; instead, the program provides data on, and a feel for, the penalties resulting from off-optimum TW operation. Constraints not considered, such as minimum free-free mode resonant frequencies of the deployed structure, may preclude selection of the maximum payload size as the best configuration. Docking loads on the deployed structure and launch loads on the stowed structure, which would also influence maximum payload size selection, have also not been included in this analysis, but can be in future refinements.

4.7.2 GROWTH CAPABILITY. Although OPTOTV is primarily used in this study to evaluate the thrust-to-weight dependent design requirements for a low thrust OTV, it can also be used for comparative evaluation of the selected or alternative large space structure systems. The LSS systems must be Shuttle compatible and transported per program options in or similar to those in Appendix 6. To implement such additional LSS systems analyses, it would be necessary to add payload subroutines to those routines already in the program. The SEPS power module algorithms in Appendix 8 provide an example of the level of detail needed to add a payload option to the program.

OTV performance and weight estimating relationships used in OPTOTV can be further refined to account for weights of avionics, electrical and fluid lines and joints, engine, tanks and tank suspensions, shell structures, adapters, and thrust vector control system.

The analysis methodology presented here for comparative OTV and LSS systems offers the following advantages:

a. It can be used to handle almost any set of interrelated sets of system performance and weight characteristics that can be defined by algorithms amenable to closed-form or iterative solutions.

b. All aspects of the analysis (i.e., synthesis and optimization of both the payload and OTV for different mission options) are fully automated in one program for efficient execution.

c. Fixed and optimized OTV and payload design parameters can be used in, or generated by the analyses. Specific parameters or sets of parameters can also be included or excluded from the program's optimization process.

4.8 RESULTS

Representative plots of OTV and payload performance, weight, and size characteristics vs. final thrust-to-weight, TW, are presented in the following:

Figures 4-10 to 4-26 for the space based radar tetrahedral truss arm (SBR-A)

Figures 4-27 to 4-36 for the space based radar tetrahedral truss ring (SBR-R)

Figures 4-37 to 4-43 for the geoplatform

Typical OPTOTV printouts from which data were taken to generate the above plots are contained, respectively, in Appendices 9, 10, and 11.

a. Baseline Parameters. Except where parametric variations are otherwise noted on individual plots (in Figures 4-15 through 4-46, or on data printouts in Appendices 8, 9, and 10), the following baseline parameters apply for the Shuttle, OTV, and payloads. The parameters in parentheses after the baseline parameters are some of the variations considered in this study.

1. Shuttle
    - Cargo bay length (LQ): 57 feet
    - Cargo bay radius (RS): 88 inches
    - Payload capability (WS): 60,000 lb (90,000) + 5,000 lb ASE

2. OTV

- Outside shell diameter (2 RS): 176 inches
- Number of burns (N): 9 (5, 2)
- Velocity requirements vs. initial thrust-to-weight (V vs. TP): Figure 4-3
- Minimum initial thrust-to-weight: 0.001
- Isp vs. thrust (IS vs. TT): Figure 4-4
- Length vs. propellant weight (LP vs. PW): Figure 4-5
- Mass fraction vs. propellant weight (MU vs. PW): Figure 4-6
- Propellant losses: Section 2.2.5
- Thrust-to-weight dynamic amplification factor ($K\phi$): 2 (1)
- Engine thrust characteristics: Constant TT (Constant TW)

3. Payloads

(a) General

- Structural construction material: Graphite Composite (Aluminum)
- Minimum primary strut diameter (DM): 2 inches
- Minimum primary strut wall thickness (TM): 0.05 inch
- Secondary strut diameter (D2): 1 inch
- Secondary strut wall thickness (T2): 0.025 inch
- Structural joint weight factor (FB): 3.218
- Hub weight fraction (ZH): 0.47 (0.65)

(b) Space Based Radar-A (SBR-A)

- Unit - area weight of lens (WL): 0.048 lb/ft^2 (0.095, 0.143) or 0.00033 lb/in^2 (0.000666, 0.00099)
- Tip weight on trusses (WT): 1 lb (400, 1000)

(c) Space Based Radar-R (SBR-R)

- Power spider weight (WN): 10 lb (15)
- Lens thickness (TL): 0.125 in. (0.086)
- Truss face width (A): 300 inches (150, 200, 400)

(d) GEO Stationary Platform

- Tip weight on truss ends (WT): 1400 lb (1200, 1500)

b. Analysis Iterations. The following list of iterative values for the more significant OPTOTV parameters provides an indication of the accuracy of the printout results.

- Primary strut diameters (DD): 0.1 inch
- Primary strut wall thickness (TD): 0.005 inch
- Truss length (LD): 10 inches
- OTV mass fraction (DV): 0.01
- Membrane thickness (TG): 0.009
- Final thrust-to-weight (TF): 0.04

c. Mission Configuration. The baseline mission configuration (or program option per Appendix 6) is ZZ = 0 for one payload, one OTV, and one Shuttle. In the SBR-A and geoplatform analyses the payload is assumed to be pre-assembled on the OTV for Shuttle delivery, while in the SBR-R analyses it is assumed that the SBR-R and OTV are delivered as separate packages in one Shuttle flight and are mated in LEO.

4.8.1 SPACE BASED RADAR-A ANALYSIS RESULTS. The following explanations and comments on the SBR-A analysis results in Figures 4-10 through 4-26 are intended to clarify the more important curve trends plus interrelationships between parameters.

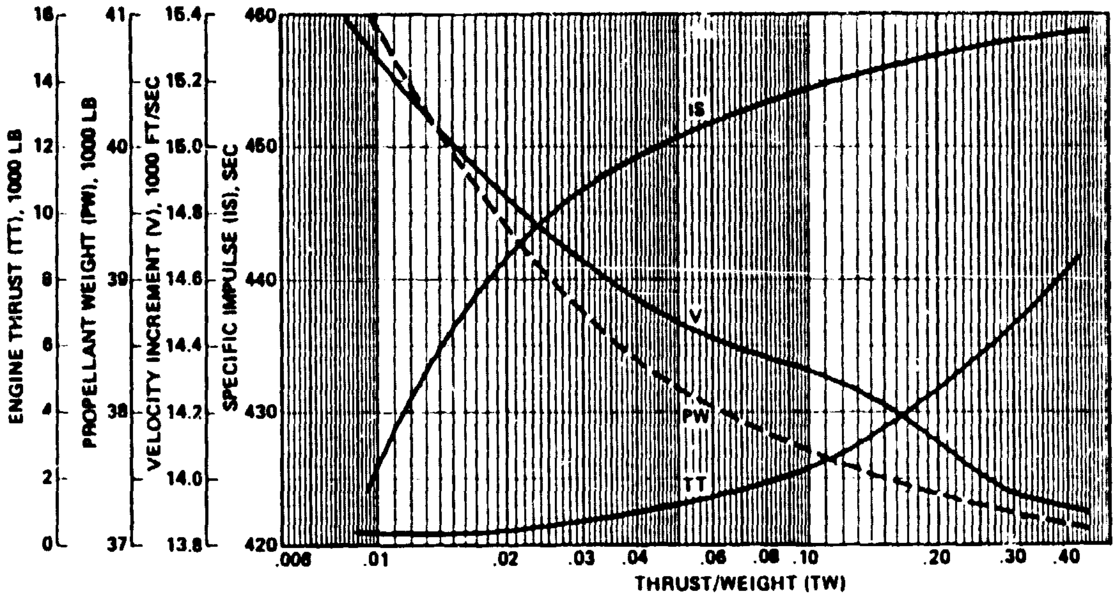


Figure 4-10. SBR-A engine thrust, propellant weight, velocity increment, and specific impulse vs. TW.

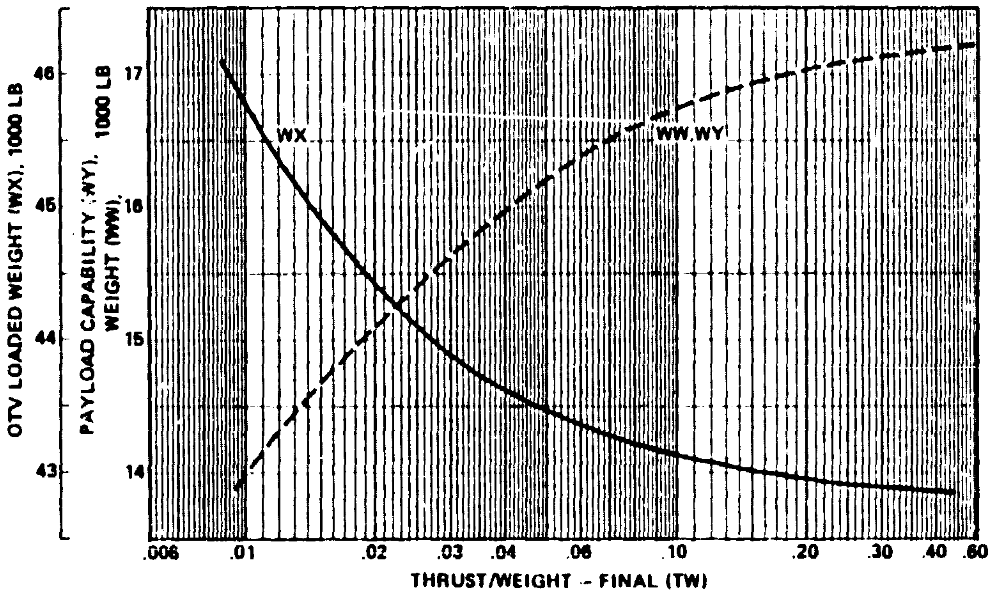


Figure 4-11. SBR-A OTV loaded weight and payload capability and weight vs. TW.

These figures show representative OTV performance parameters vs. thrust-to-weight (TW) for an SBR-A baseline payload. Note that the payload capability (WY) constantly ir ›ases over the selected TW range; however, as will be seen later, the size of the ! ..-A does not follow a similar trend. The parameters in these figures define OTVs that have been optimized at specific TW values along with mated SBR-A baseline configurations. Improvements in specific impulse (IS) and reductions in required velocity increments (V) are among the primary contributors to shapes of the PW, WX, and WY curves.

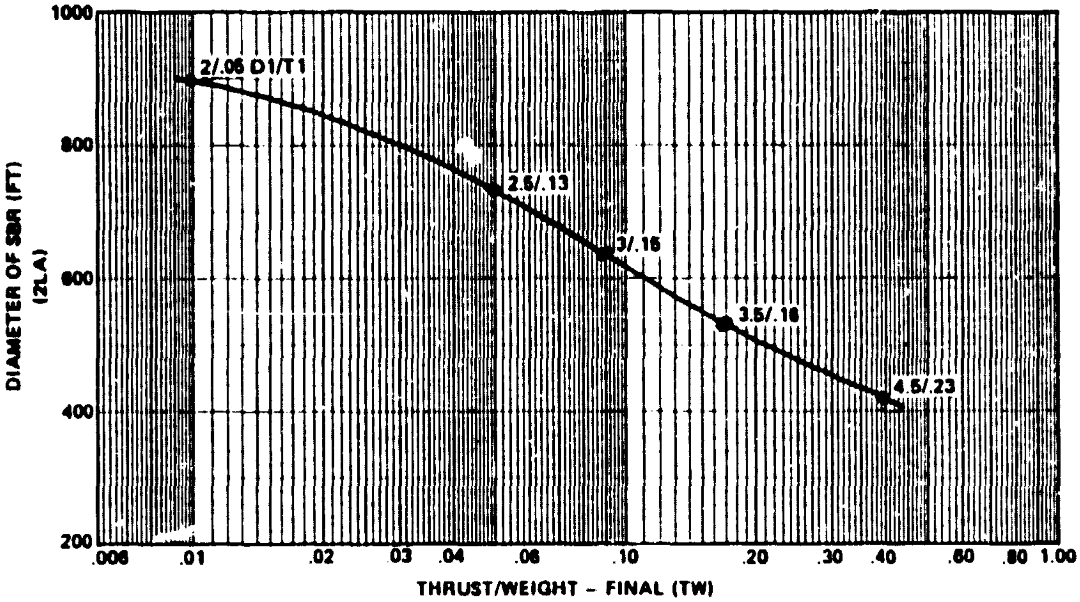


Figure 4-12. SBR-A. 1 payload, 1 Shuttle. WS = 60,000 lb, diameter vs. TW.

The largest SBR-As that can be delivered to LEO by the Shuttle (having a 60,000 lb payload capability) are identified here as a function of TW. Primary strut diameters and wall thicknesses resulting from SBR optimization are shown parametrically at several points. In this case, the entire Shuttle's weight and volume payload capability are used.

This curve is intended to provide an upper reference limit to SBR-A size that is achievable exclusive of OTV payload capability.

Examination of the D1/T1 data shows that as TW increases the optimum D1 and T1 increase. These increases are made in a manner that causes the full Shuttle payload weight and volume capabilities to be used for each TW.

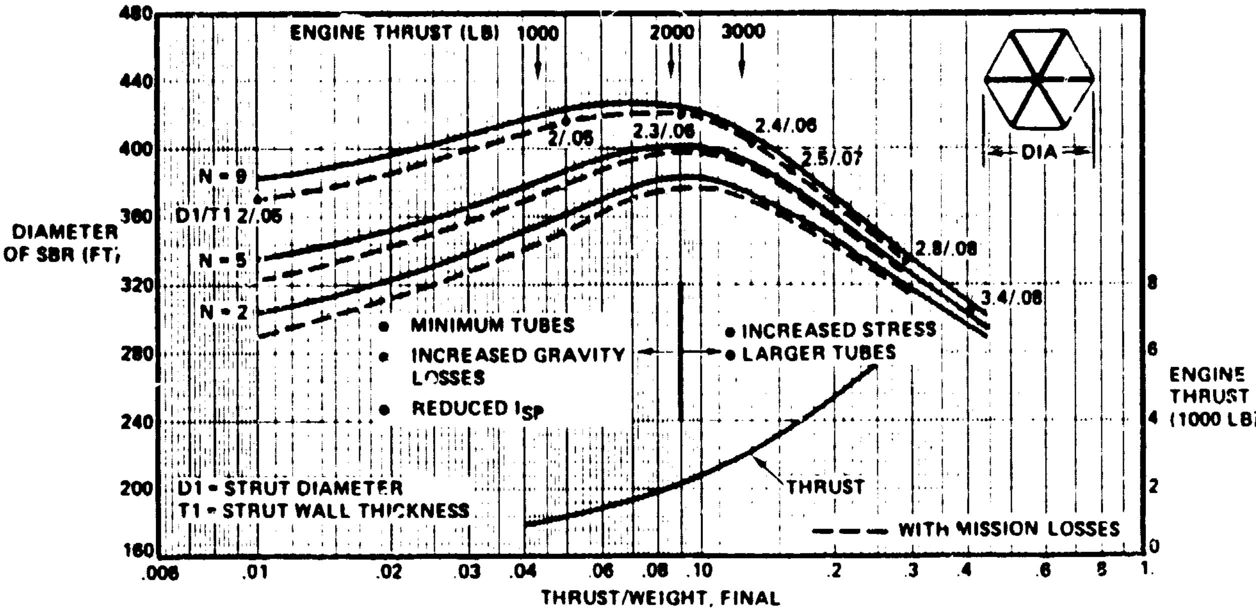


Figure 4-13. Effect of engine thrust & number of burns on size of SBR-A.

With the OTV and payload in one Shuttle, this figure shows OPTOTV-generated optimized (maximum) SBR-A diameters vs. TW for the SBR-A baseline and the SBR-A baseline with N = 5 and 2 burns. The largest diameter for the baseline configuration is developed at about TW = 0.07, at TW = 0.08 for N = 5, and TW = 0.09 at N = 2. These curves also show the relative magnitudes of the mission losses (dashed lines) as well as the TW values at which the payload is limited by the Shuttle's weight and volume limitations.

A partial explanation for the shape of these curves, referring to Figures 4-10, 4-11 and 4-13, is as follows:

For small values of TW the OTV's payload capability (WY) is low and stage weight (WX) is high. Both of these factors tend to make the SBR-A diameter (2LA) small and generally cause the OPTOTV-selected primary strut diameters (D1) and wall thicknesses (T1) to be at minimum allowable values. As the TW is increased between 0.01 and 0.07, the rates at which WY increases and WX decreases are more dominant in increasing allowable SBR-A weights and stowed volumes than the rate at which increasing engine thrust (TT) causes increases in required structural dimensions D1, T1. These in turn increase the payload weight (WW) and stowed length (LC). This process continues, with increasing TW values, until the rates of increase in TT and decrease in WX sufficiently decelerate to reverse the trend. With TW values greater than 0.10, improvements in OTV stage performance tend to be small compared to required increases in D1 and T1 to carry increasingly higher strut buckling loads. Therefore, the size of the SBR-A decreases markedly with increasing TW values beyond this point.

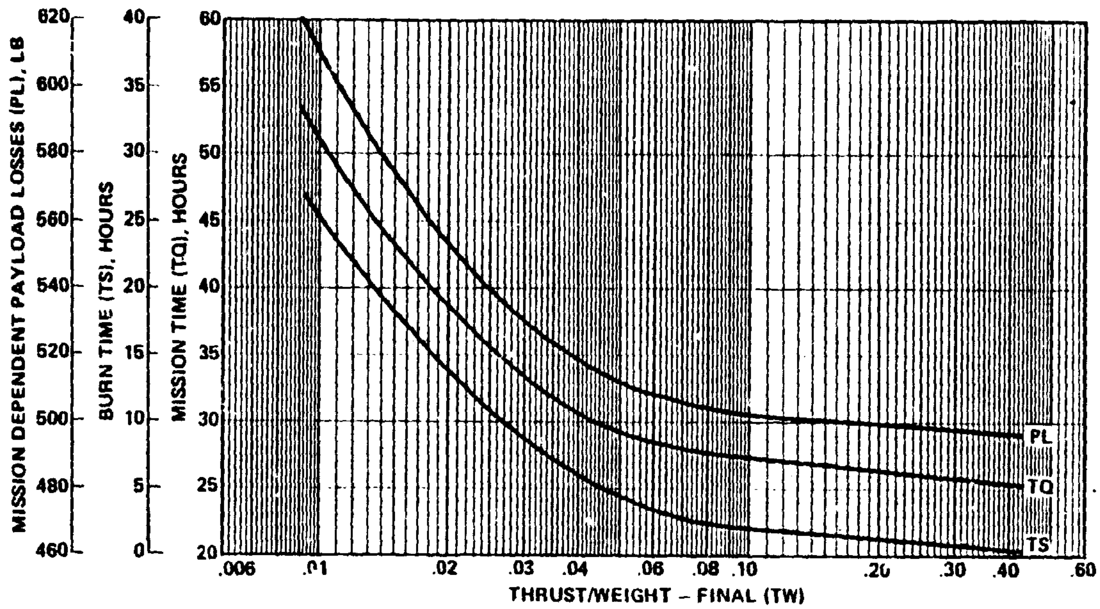


Figure 4-14. SBR-A. Mission dependent losses, burn time, and mission time vs. TW.

The mission-dependent losses and burn and mission times vs. TW are shown in Figure 4-14. As expected, these related parameters decrease with increasing TW.

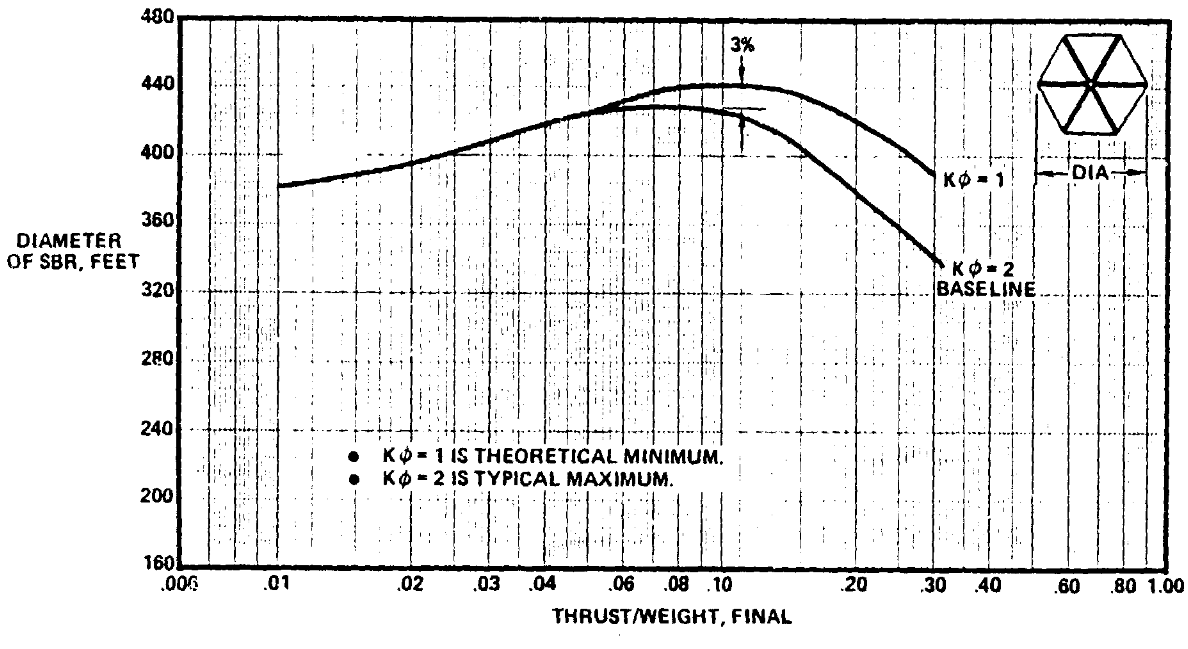


Figure 4-15. Effect of dynamic factor (Kϕ) on size of SBR-A.

This graph shows the effects of changes in the thrust amplification factor (Kϕ). Amplification factors greater than 2 are not likely. If Kϕ were close to 1, the optimum TW would be closer to 0.107 than TW - 2.07 based on Kϕ = 2.

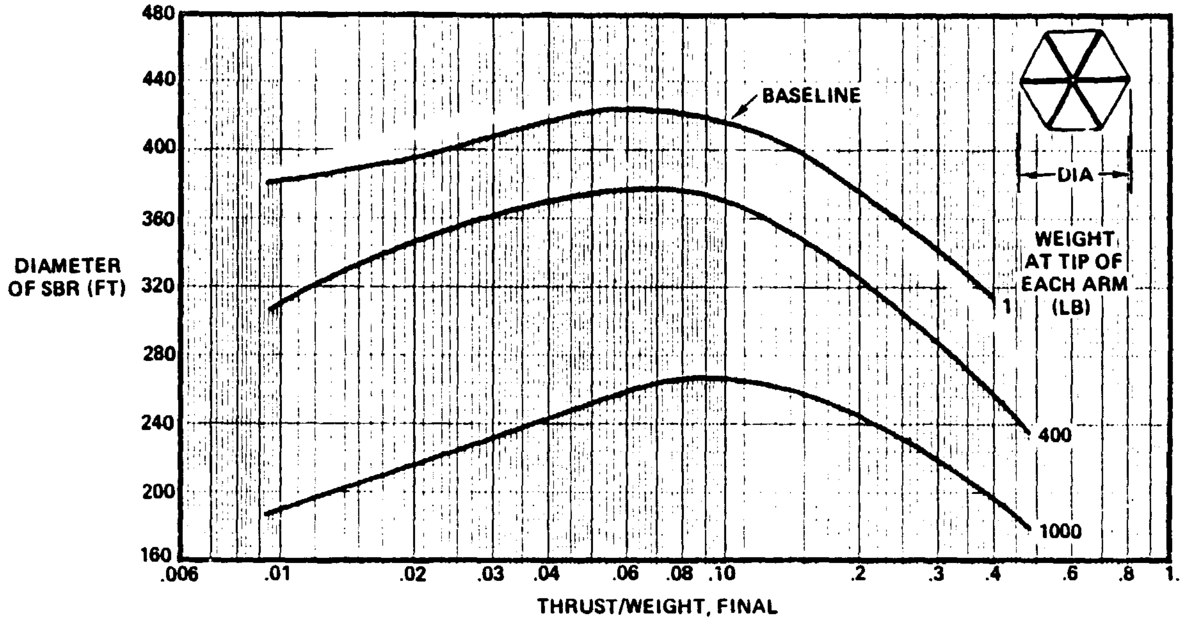


Figure 4-16. Effect of tip weights on size of SBR-A.

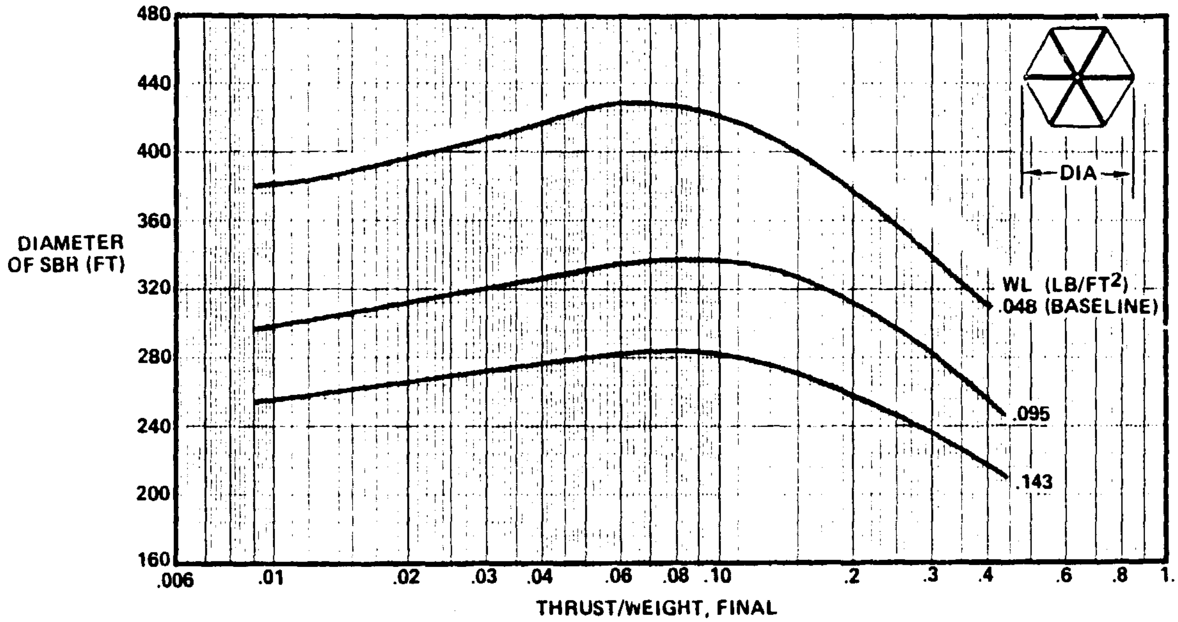


Figure 4-17. Effect of lens density (WL) on size of SBR-A.

Figures 4-16 and 4-17 show the effects of truss end weights (WT) and unit area weights of lens (WL).

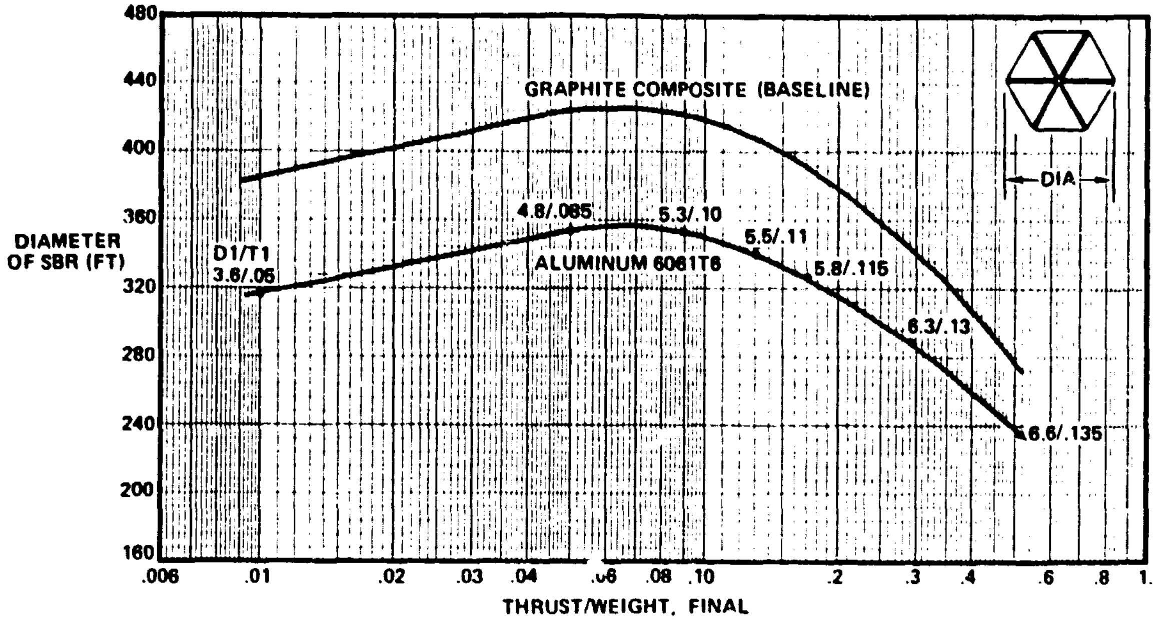


Figure 4-18. Effect of truss material on size of SBR-A.

The size penalties resulting from use of aluminum as a construction material are shown here.

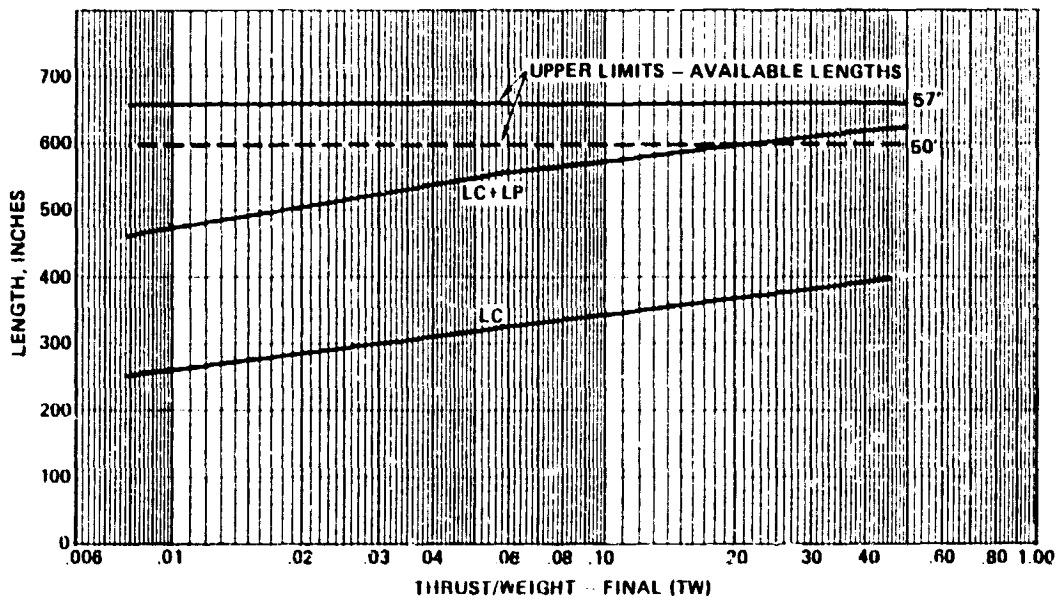


Figure 4-19. SBR-A. (LC) length of stowed payload and (LP) length of OTV vs. TW, compared to cargo bay upper length limits.

The packaged lengths of the SBR payload (LC) and OTV (LP) are shown here vs. TW and compared with the 57-foot upper limit available in the Shuttle cargo bay.

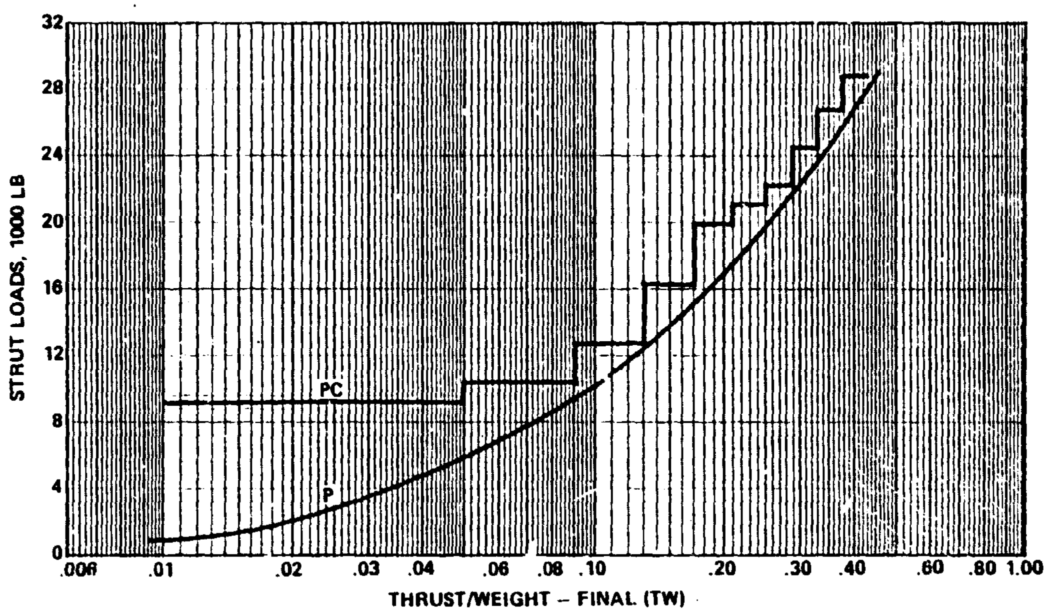


Figure 4-20. SBR-A. (PC) critical longeron buckling load and (P) induced longeron load vs. TW.

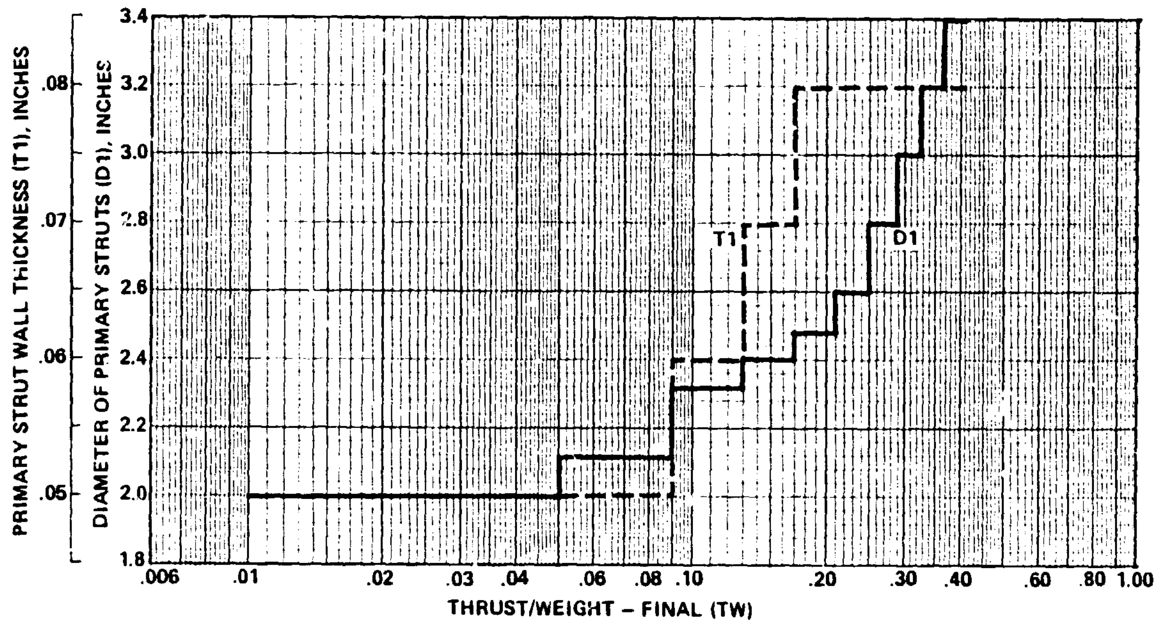


Figure 4-21. SBR-A. (T1) primary strut wall thickness and (D1) primary strut tube diameter vs. TW.

Figures 4-20 and 4-21 show the OPTOTV-generated induced (P) and critical (PC) longeron loads and the stepwise increased D1 and T1 values related to PC. The OPTOTV analysis strategy is designed to select D1 and T1 values that minimize structural weight and maximize (LA) area.

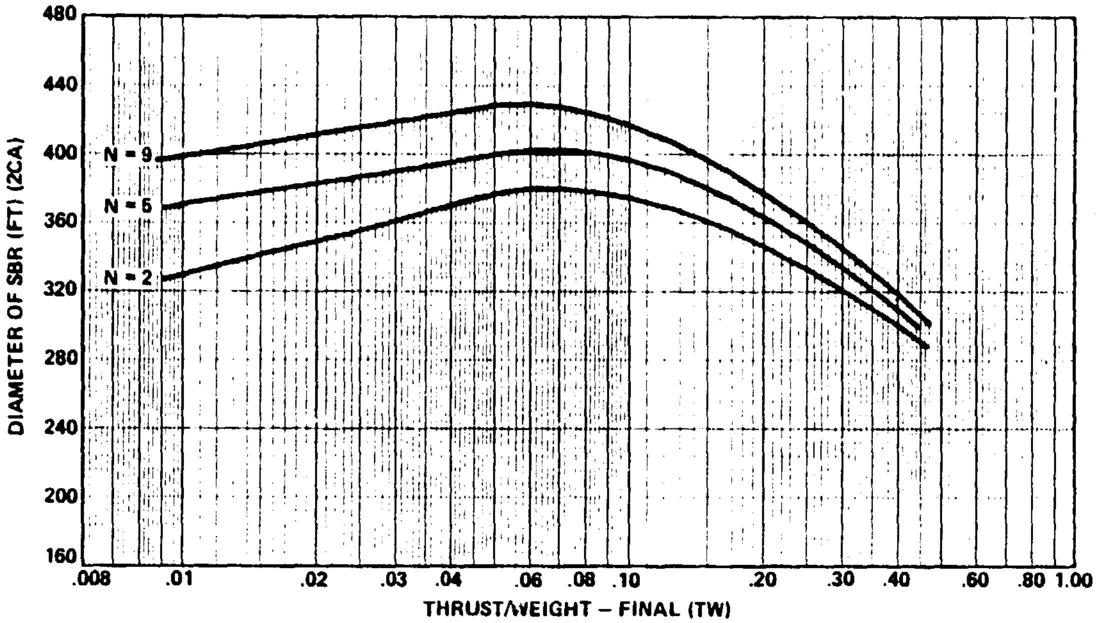


Figure 4-22. SBR-A. (IS) specific impulse held constant at 450 sec and N = 9, 5, 2. Diameter vs. TW.

Effects of holding the specific impulse (IS) constant at 450 seconds is shown here. When compared with Figure 4-13 it is evident that the greatest effects are at low TW values where, per Figure 4-10, the normally computed IS values are lower than 450 seconds.

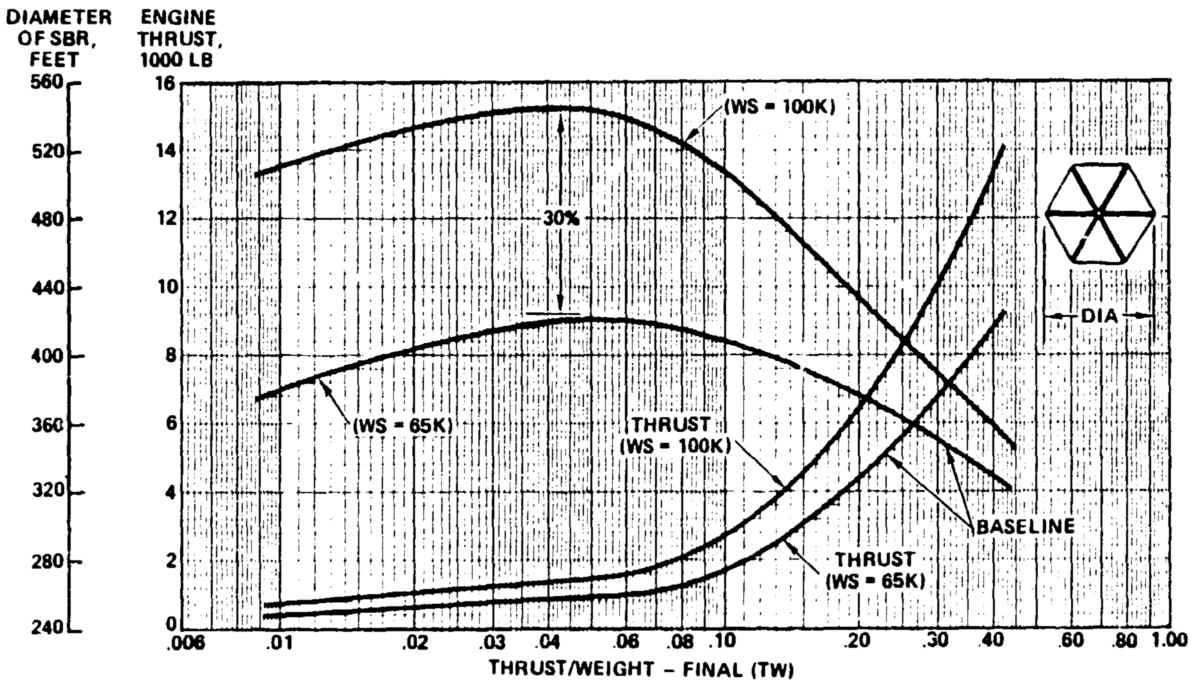


Figure 4-23. Effect of Shuttle capability (WS) on size of SBR-A.

Figure 4-23 shows the significant effects on SBR-A size and OTV engine thrust (TT) of increasing Shuttle payload capability (WS).

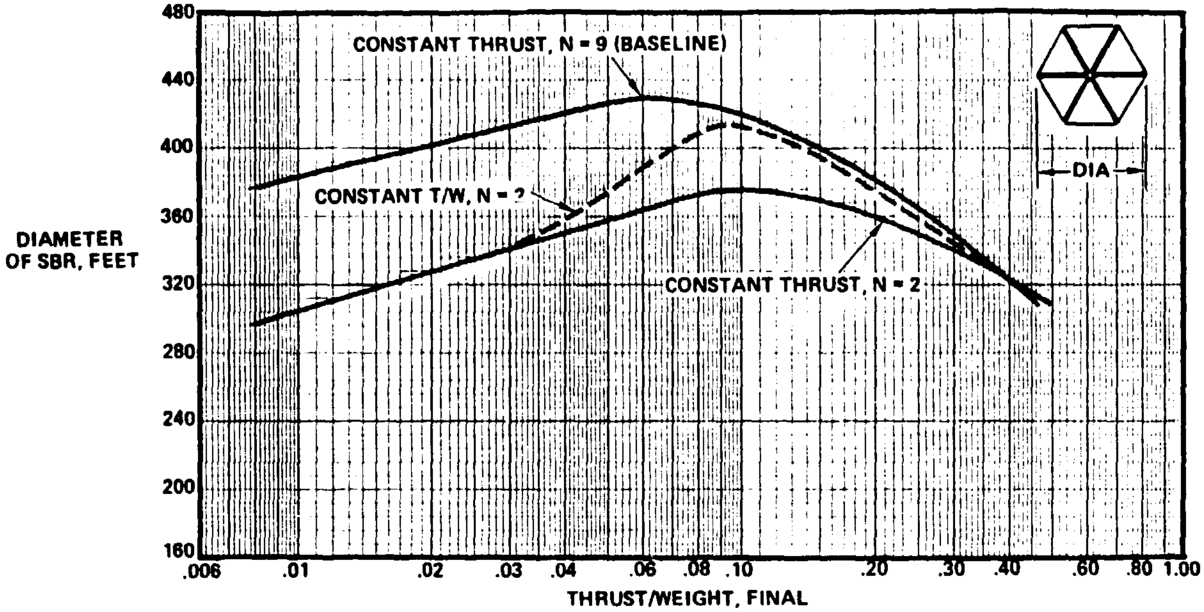


Figure 4-24. Effect of constant acceleration (variable thrust) on size of SBR-A.

Shown here are relative effects of constant TW and constant-thrust OTV engine performance for N = 2 burns. It is evident that constant TW and N = 2 can almost produce as large an SBR as the baseline configuration, but is much more sensitive to thrust-to-weight.

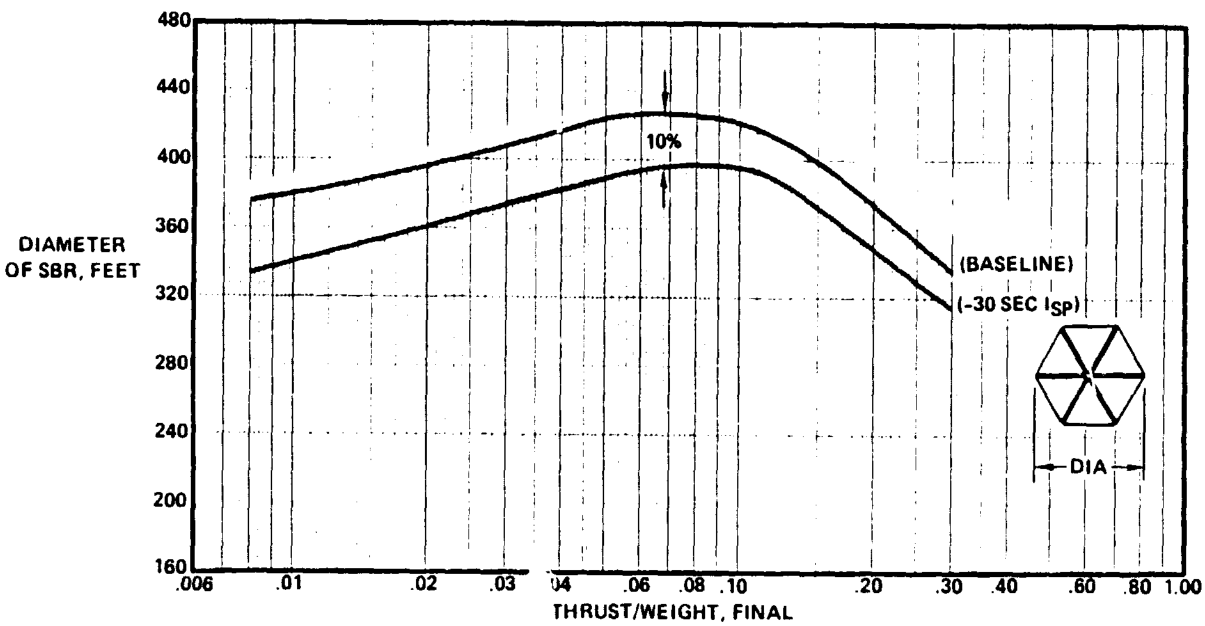


Figure 4-25. Effect of reduced engine performance on size of SBR-A.

Reducing the computed specific impulse (IS) by 30 seconds has an important effect on reducing SBR size (2LA).

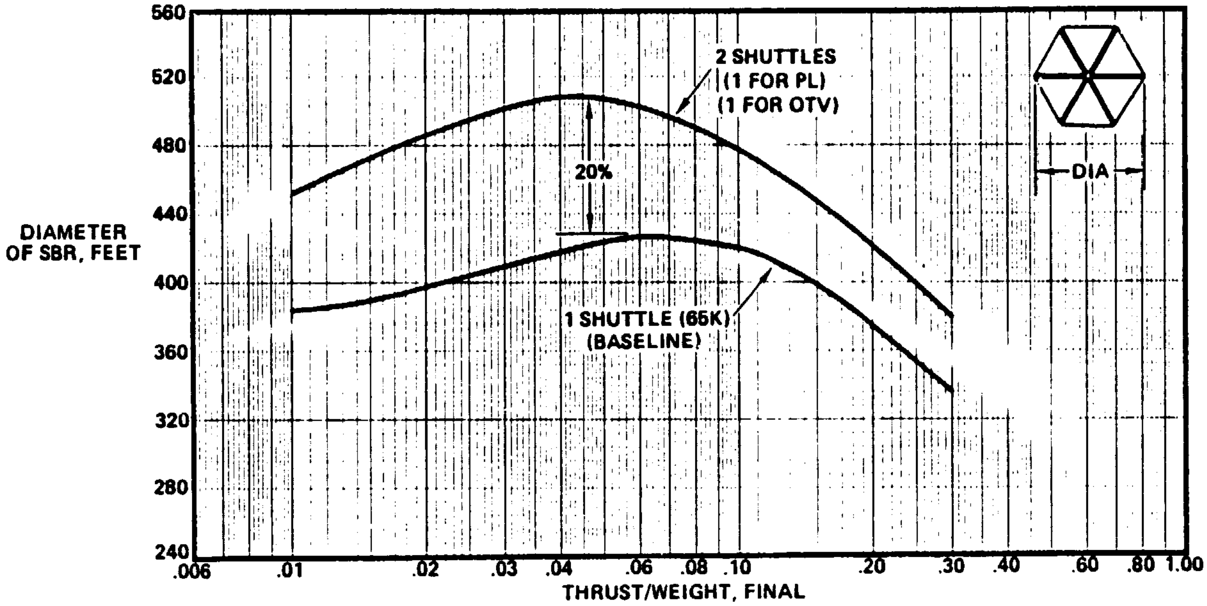


Figure 4-26. Effect of number of Shuttles on size of SBR-A.

Figure 4-26 shows the effects of using two Shuttle flights, one for the OTV and one for the SBR-A. The SBR-A sizes that can be achieved are smaller than those in Figure 4-12 in which the payload limitation of the OTV is not a limiting factor as it is in this case.

The graph also indicates that the LSS sizes that can be achieved are smaller in terms of total area than would result from two baseline flights (OTV and LSS together in each Shuttle). Two baseline flights would produce a 200% area increase rather than a 144% increase (which the indicated 20% size increase indicates). This neglects the docking requirements for two separate payloads as well as stowing efficiency losses and payload losses for rendezvous ΔV. Further study would be needed to assess these requirements.

4.8.2 SPACE BASED RADAR-R ANALYSIS RESULTS. The SBR-R analysis results resemble those of the SBR-A as the following figures indicate.

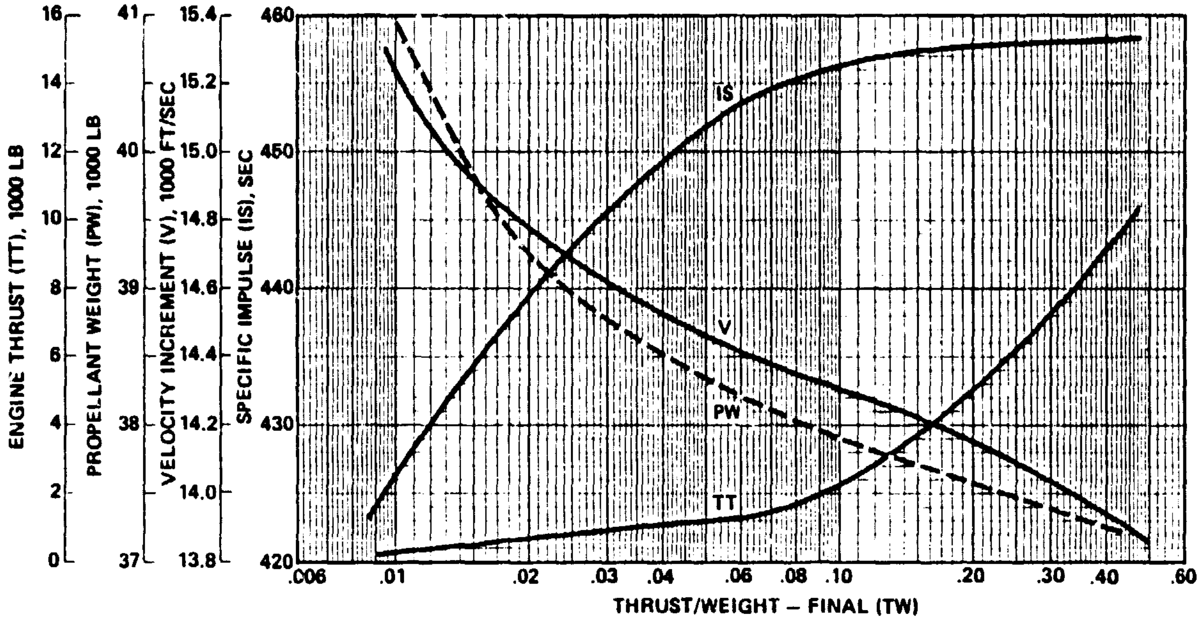


Figure 4-27. SBR-R. Engine thrust, propellant weight, velocity increment, and specific impulse vs. TW.

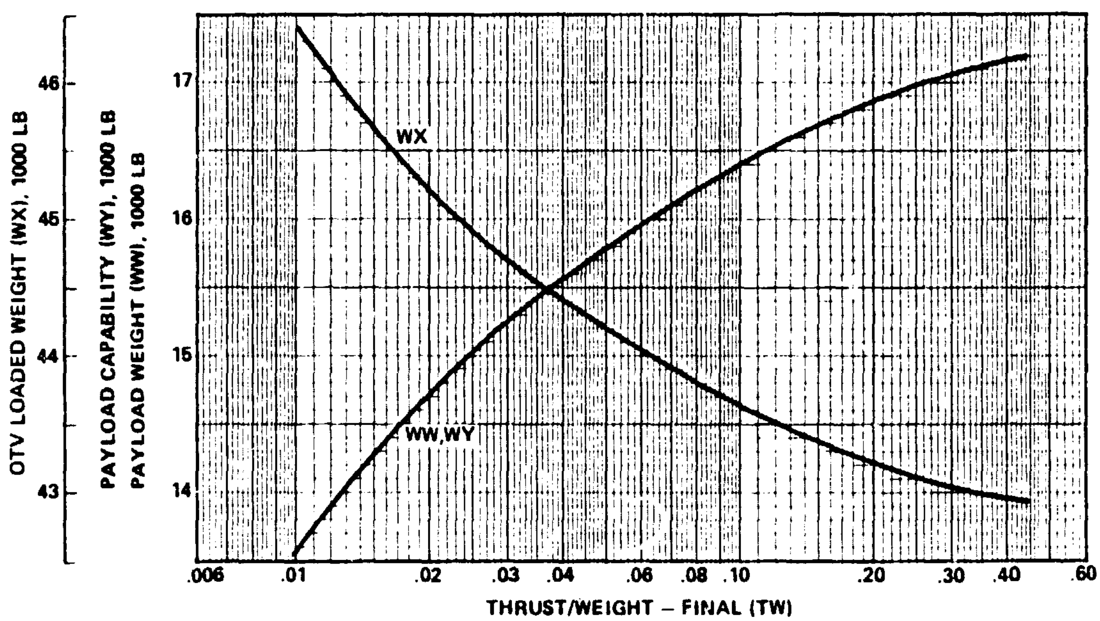


Figure 4-28. SBR-R. OTV loaded weight and payload capability and weight vs. TW.

These are very similar to Figures 4-10 and 4-11.

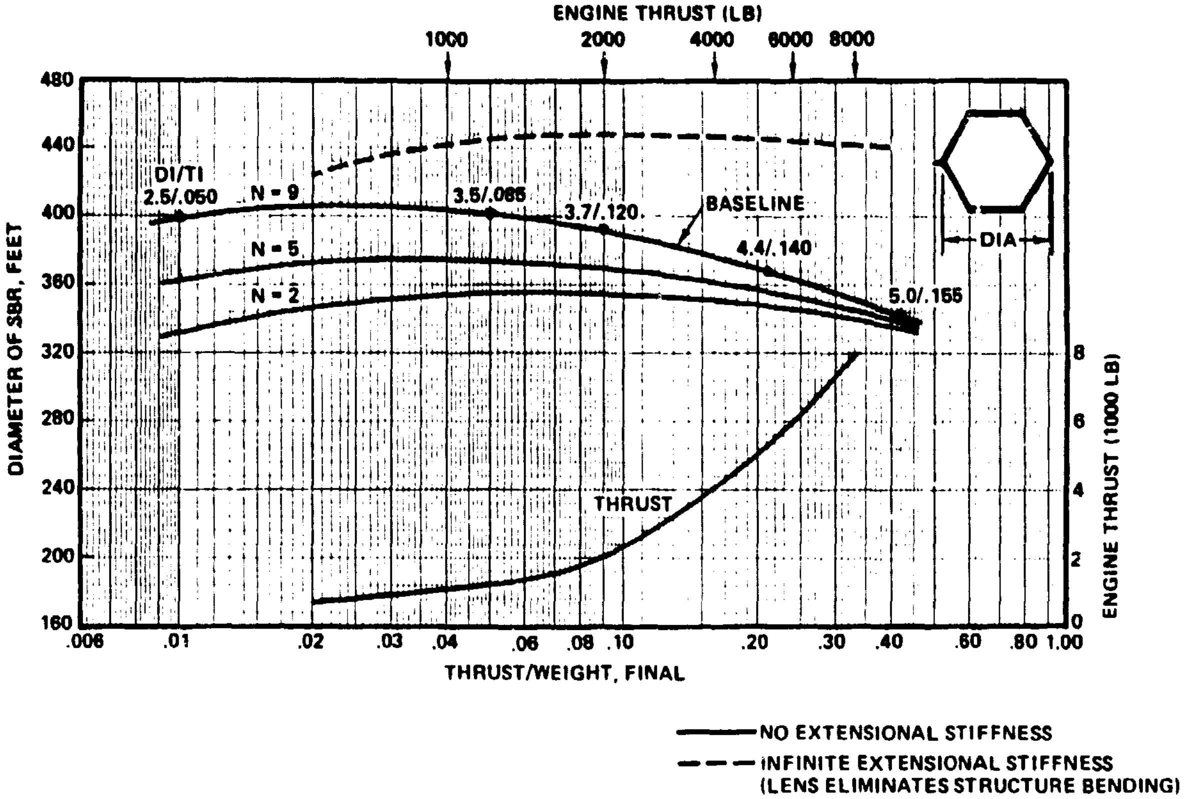


Figure 4-29. Effect of engine thrust and number of burns on size of SBR-R.

In comparison with Figure 4-13 it is evident that SBR-R size variations (2LA) for different number of burns (N) are not as TW dependent as they are for the SBR-A. This is due to structural (stress) considerations and the relatively smaller percent total LSS weight in the truss structure.

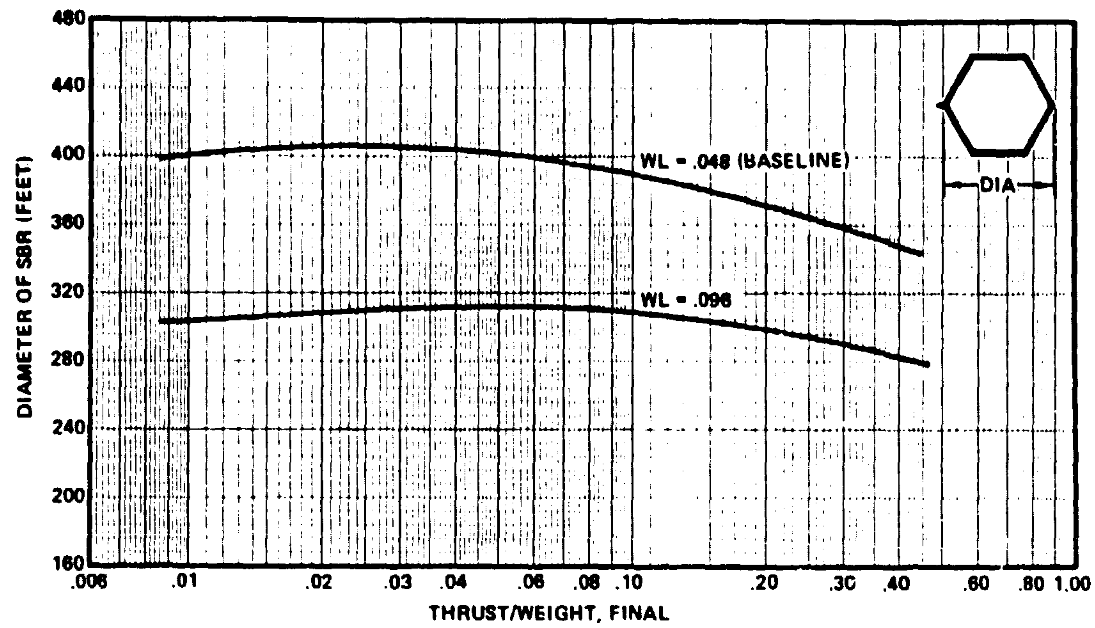


Figure 4-30. Effect of lens density (WL) on size of SBR-R.

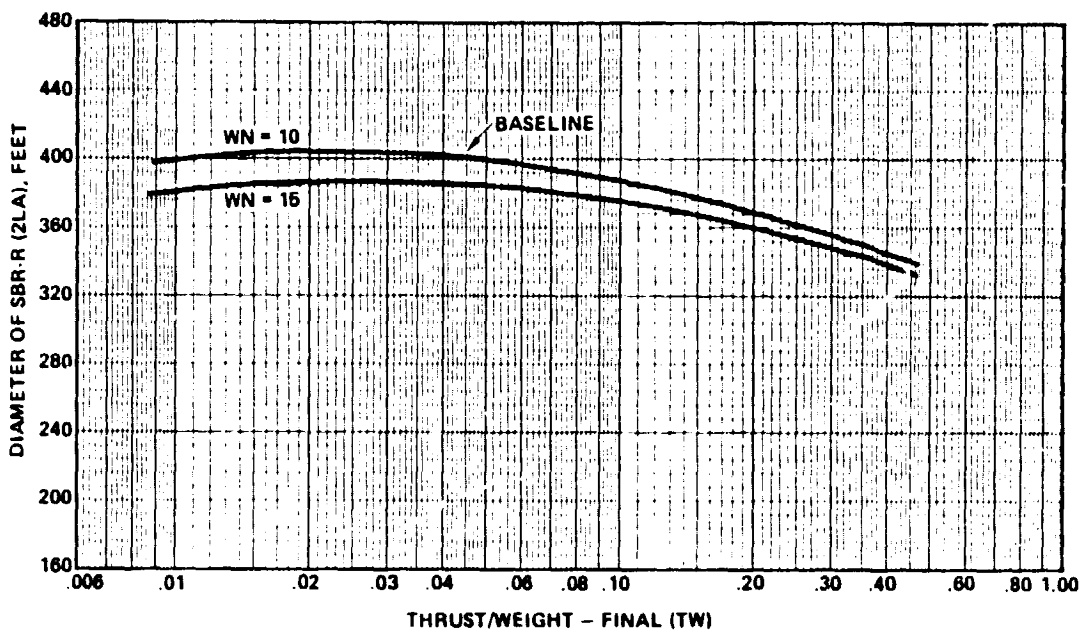


Figure 4-31. SBR-R. (WN) power spider weight = 10 and 15 lb. Diameter vs. TW.

Figures 4-30 and 4-31 indicate, respectively, the influences, relative to the SBR-R baseline configuration, of changes in lens unit area weight (WL) and power spider weight (WN).

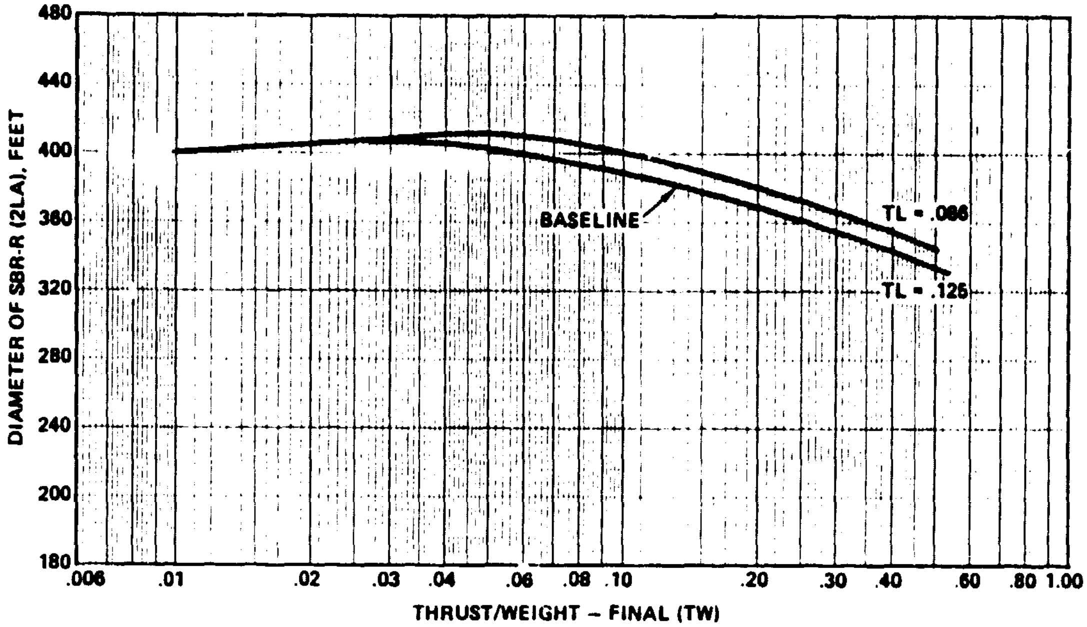


Figure 4-32. SBR-R. (TL) lens thickness 0.086 and 0.125 inch. Diameter vs. TW.

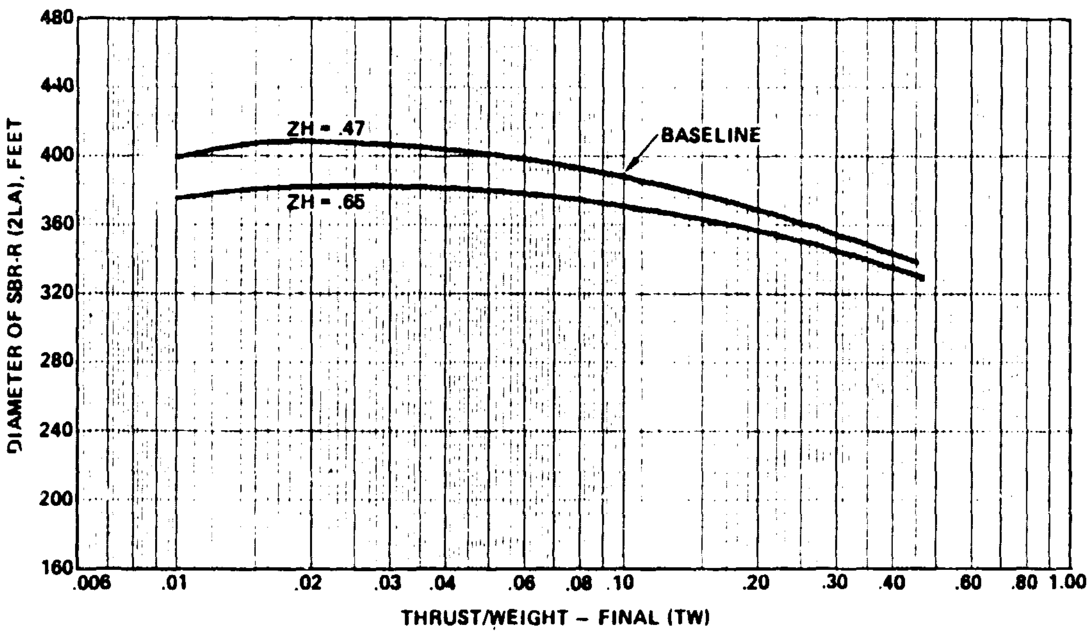


Figure 4-33. SBR-R. (ZH) hub weight fraction 0.47 and 0.65 inch. Diameter vs. TW.

Figures 4-32 and 4-33 indicate, respectively, the influences, relative to the SBR-R baseline configuration, of changes in lens thickness (TL) and hub weight (ZH).

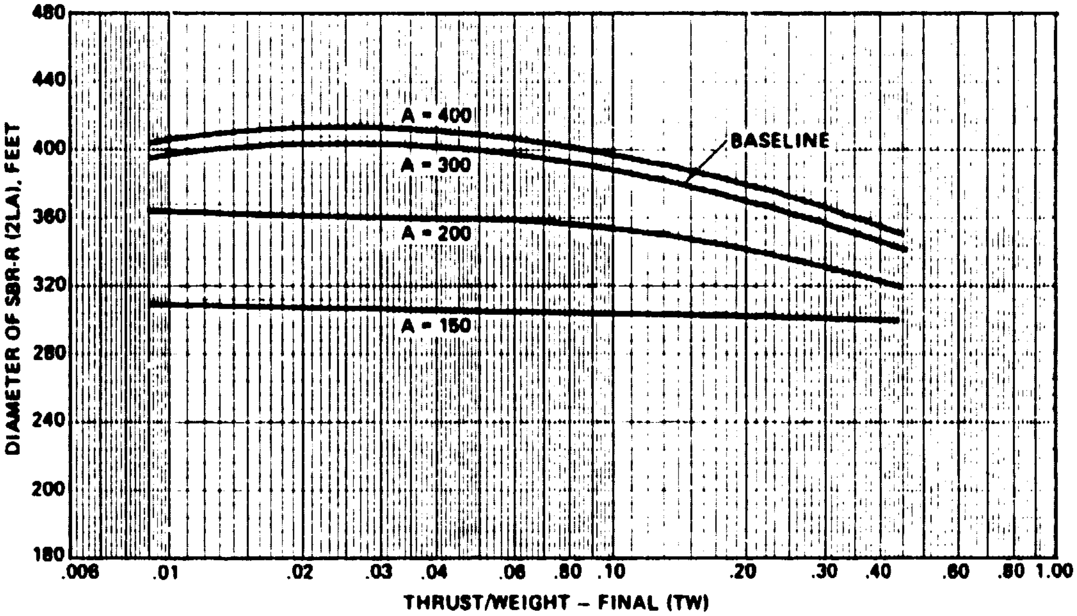


Figure 4-34. SBR-R. (A) truss face width = 150, 200, 300, and 400 inches. Diameter vs. TW.

The effect of truss face width (A) in this figure is explained by the fact that, as A is increased, a greater volumetric portion of the Shuttle cargo bay is used. The size of the SBR-R is accordingly increased up to the point at which SBR-R and OTV weight and performance limitations become significant factors.

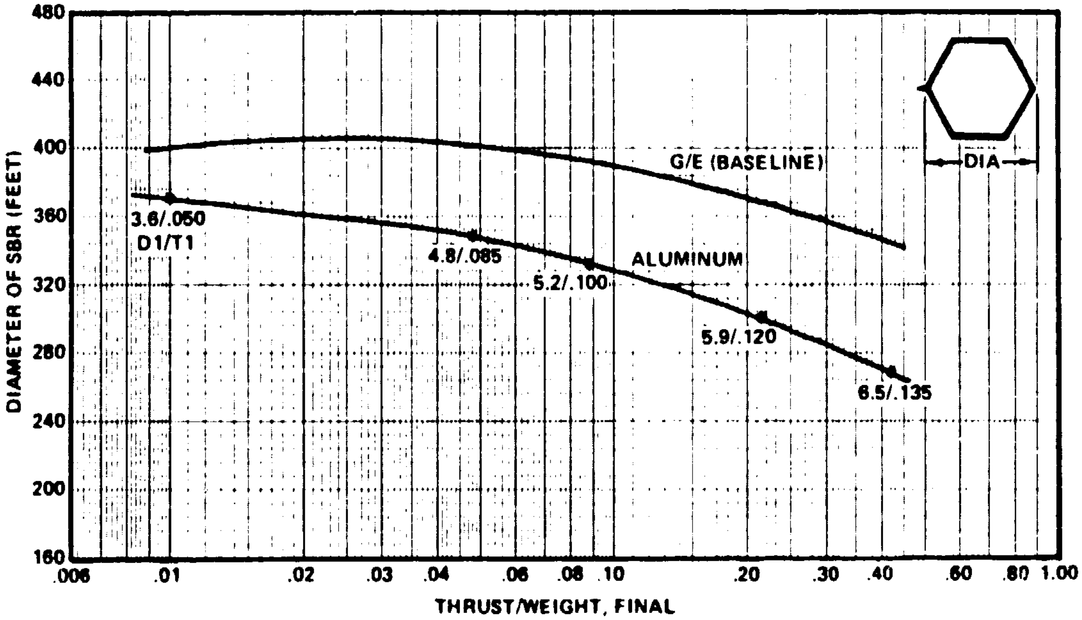


Figure 4-35. Effect of truss material on size of SBR-R.

Effects of change from graphite epoxy to aluminum as a construction material, as shown in this figure, are comparable to those shown in Figure 4-23 for the SBR-A.

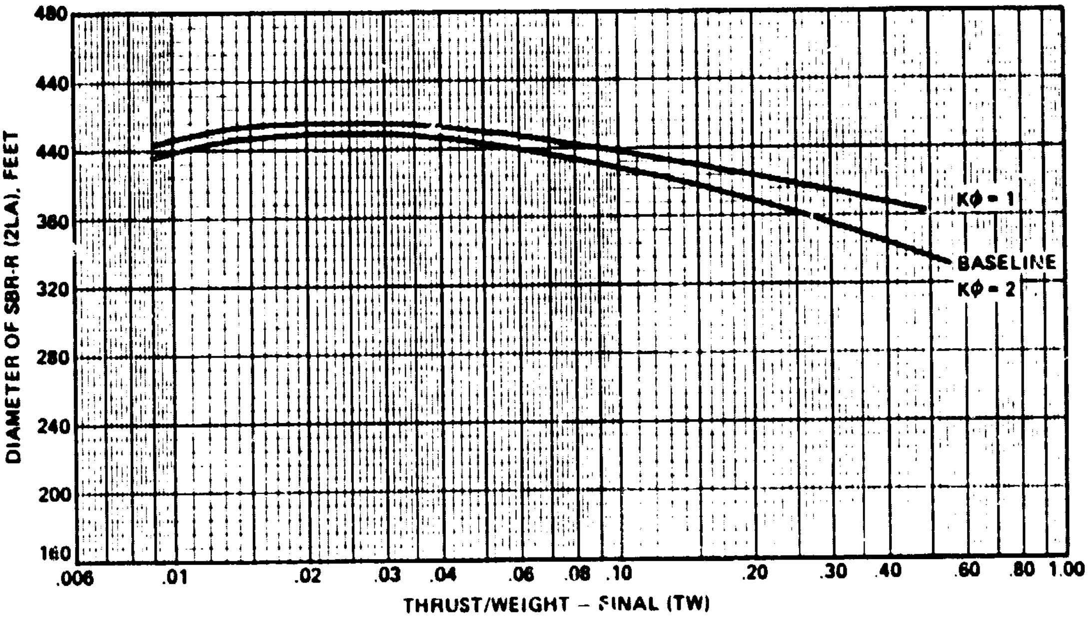


Figure 4-36. SBR-R. $K\phi$ = 2 and 1.

The effects of reducing thrust amplification ($K\phi$) from 2 to 1 for the SBR-R are shown in this figure. The benefits of low thrust amplification tend to occur at higher TW values in this case than they do in the SBR-A because of differences in structural characteristics and smaller fraction of the overall SBR-R comprising the load-carrying structure.

4.8.3 <u>GEOPLATFORM ANALYSIS RESULTS</u>. The following explanations and comments on the geoplatform analysis results parallel some of those for the SBR-A and SBR-R.

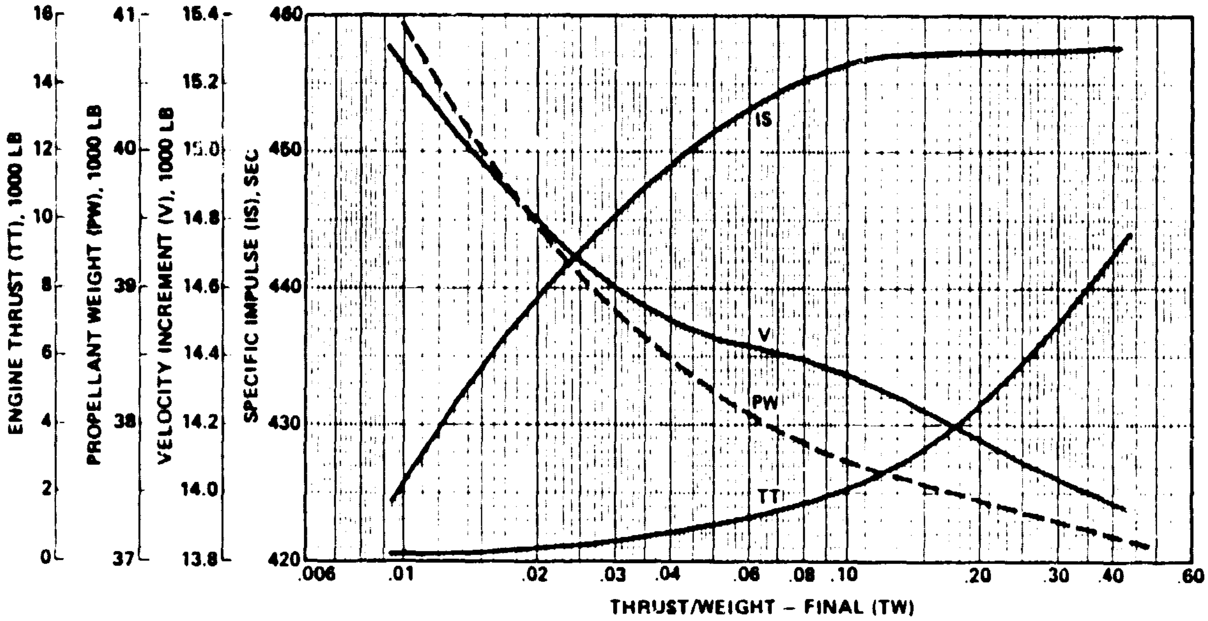


Figure 4-37. Geoplatform. Engine thrust, propellant weight, velocity increment, and specific impulse vs. TW.

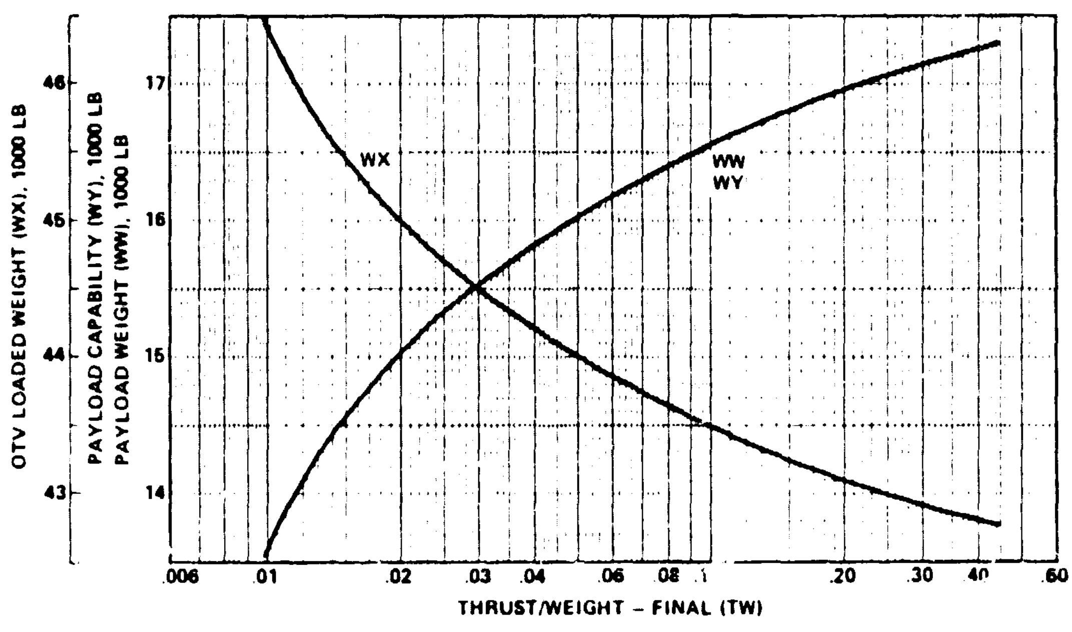


Figure 4-38. Geoplatform. OTV loaded weight and payload capability and weight vs. TW.

These figures are similar to Figures 4-10 and 4-11. The same explanations and comments apply.

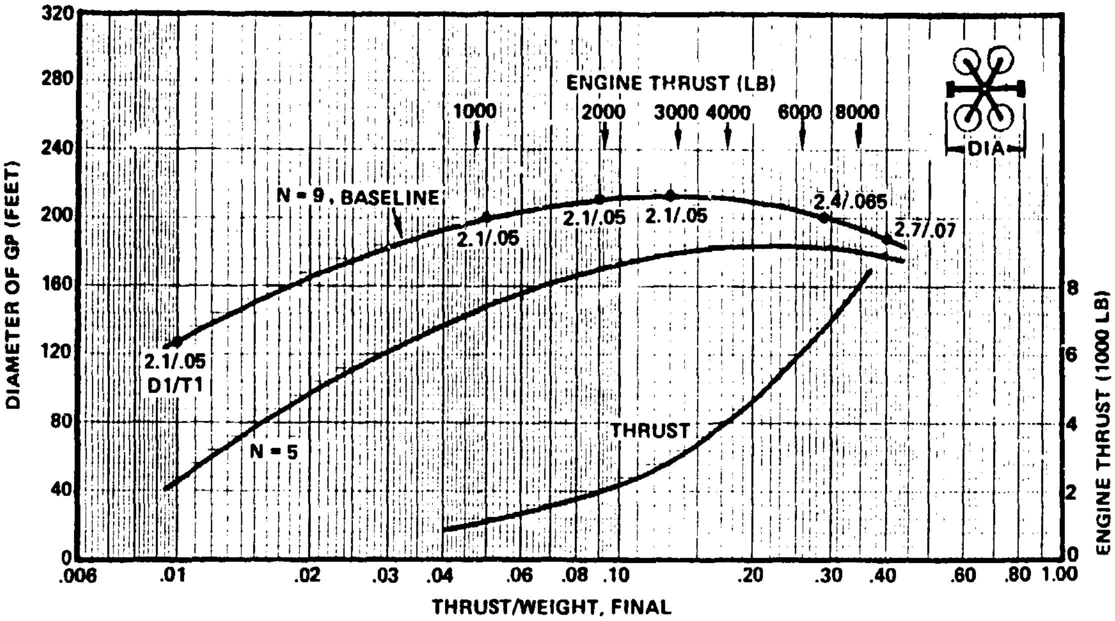


Figure 4-39. Effect of engine thrust and number of burns on size of geoplatform.

These curves, like those in Figure 4-13, identify the TW values producing the maximum size structures for number of burns N = 9 and 5. In this case, TW = 0.13 produces the peak geoplatform size (compared with TW = 0.07 for the peak SBR-A size with N = 9).

Note that the structure sizes (2LA) are considerably smaller than those for the SBR-A or SBR-B. This being primarily due to the larger truss end weights (WT = 1400 lb). Fall-off of size with increasing TW above 0.17 is also not as pronounced as in the case of the SBR-A for TW values above 0.07.

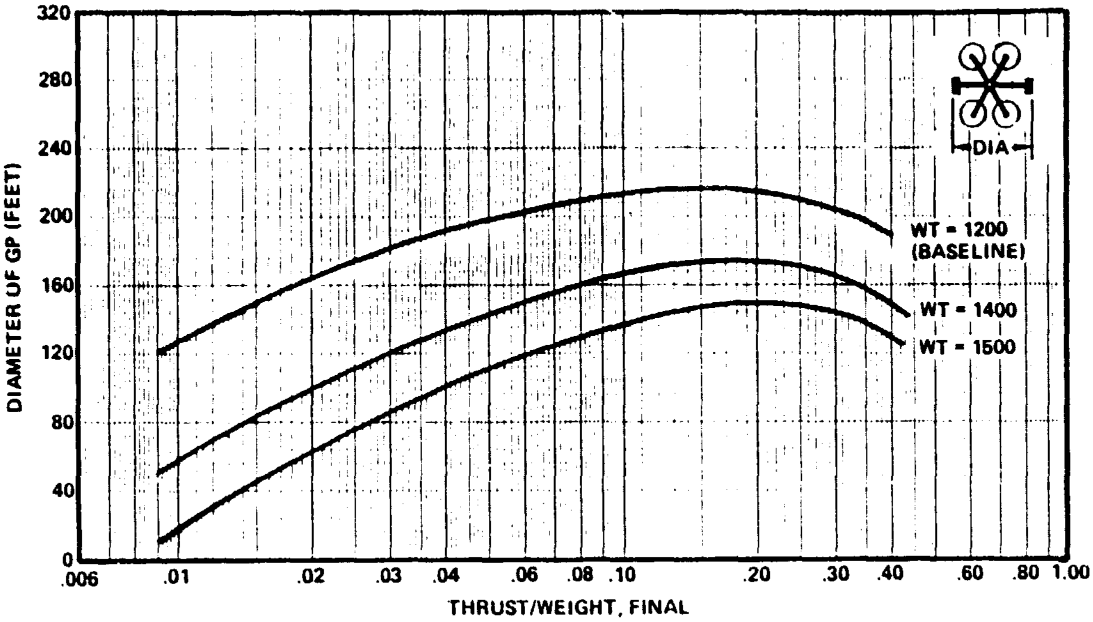


Figure 4-40. Effect of tip weights (WT) on size of geoplatform.

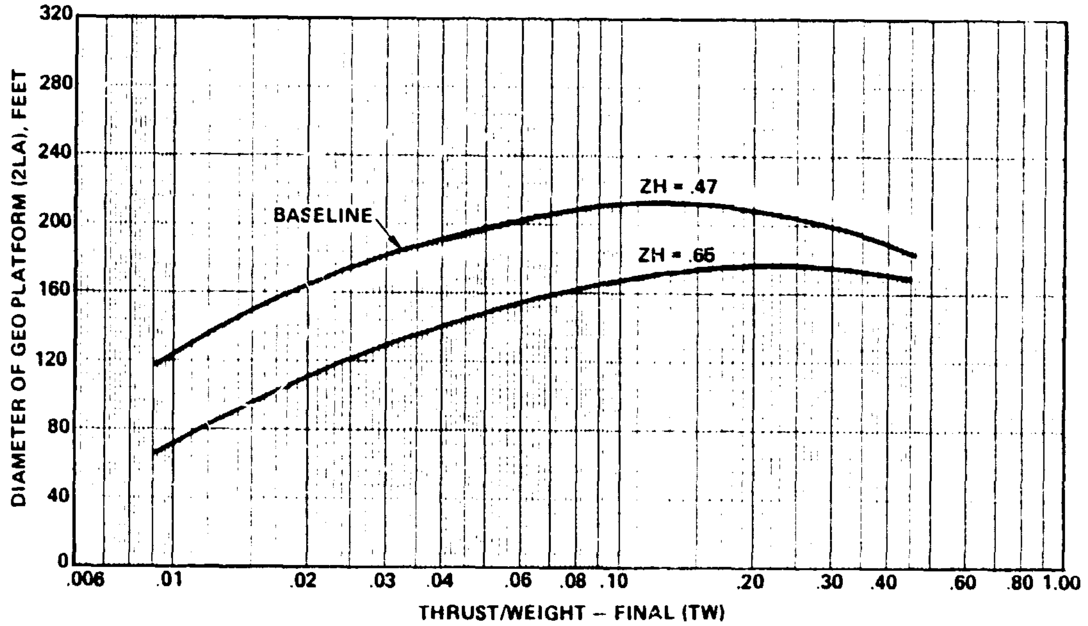


Figure 4-41. Geoplatform. (ZH) hub weight fraction = 0.47 and 0.65 inch, WT = 1200 lb. Diameter vs. TW.

Figures 4-40 and 4-41 show the effects of changes in truss end weights (WT) and hub mass fraction (ZH).

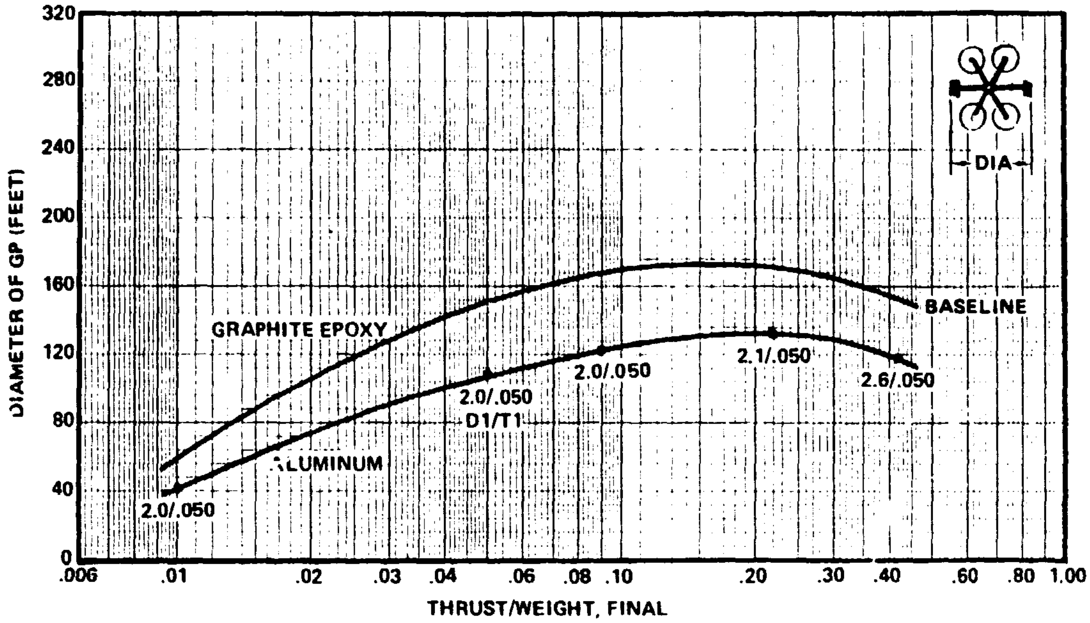


Figure 4–42. Effect of truss material on size of geoplatform.

Influence of aluminum as the construction material is shown here. Compared to the SBR-A and SBR-B, the structural weight, in this case, is a relatively small fraction of the total LSS weight. The OPTOTV-selected strut sizes (D1 and T1) also tend to be relatively closer to their minimum values. As a consequence, the percent reduction in size due to use of aluminum is greater than in the cases of the SBR-A and SBR-B. If the minimums, DM and TM, were reduced, then OPTOTV would have selected smaller D1 and T1 values (i. e., D1 = DM = 2.00 in. and T1 = TM = 0.05 in.) between TW = 0.01 to 0.1.

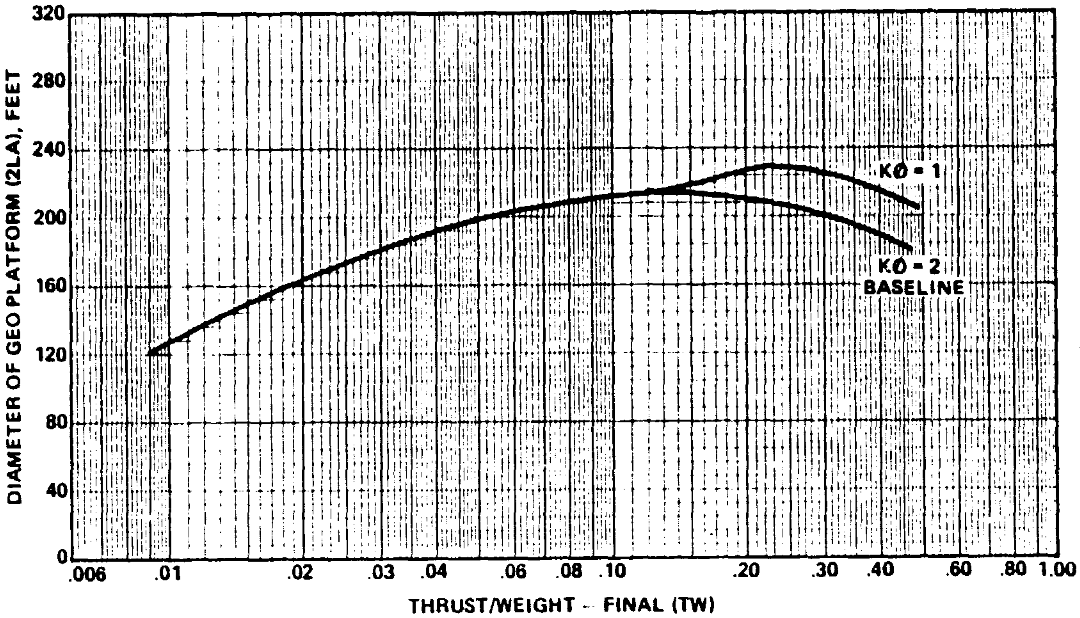


Figure 4-43. Geoplatform. Kϕ = 2 and 1.

The benefits of reducing the thrust amplification factor (Kϕ) from 2 to 1 start at TW > 0.15. Since the structure forms a smaller part of the geoplatform than it does in the SBR-A, the effects of increasing TW occur at larger TW values, where minimum strut sizes (DM) and wall thicknesses (TM) are exceeded. The benefits of low Kϕ at sufficiently high TW values are approximately proportional to the mass fraction contained in the GP and SBR-A load-carrying structures.

4.8.4 SUMMARY ANALYSIS RESULTS

The baseline weight summaries at optimum TW in Table 4-2 are based on data in Figures 4-15 through 4-43, as well as Appendices 9, 10, and 11. Significant departures are possible from the values in Table 4-2 depending on differences between selected mission, payload, and OTV parameters and those parameters used to define the baseline configurations.

The SBR-A and SBR-R results indicate that the optimum-thrust OTV design is at or near final thrust-to-weight (TW) = 0.05 to 0.07 or thrust levels (TT) of 1000 to 1500 lb.

For the geoplatform application with structural sizes peaking at TW = 0.13, the optimum engine thrust (TT) is near 3000 lb.

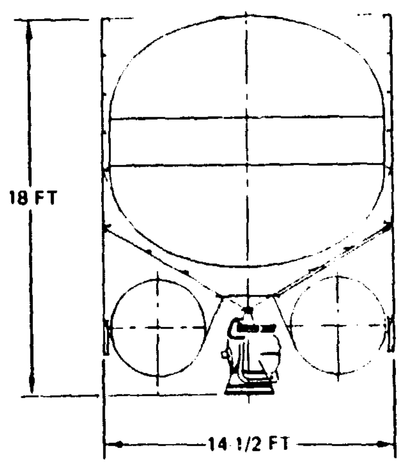
Table 4-2. Weight summaries for baseline configurations at optimum thrust-to-weight.

	SBR-A	Geoplatform	SBR-R
Thrust-to-weight	0.07	0.13	0.05
Weights, lb			
Total Payload	15,930	16,799	15,204
Structure	2,069	816	1,062
Nodes (joints)	4,590	1,811	2,990
Lens (antenna)	4,245	—	6,291
Hub (core)	5,021	6,972	4,861
Truss End, Total	6	7,200	—
OTV	44,070	44,201	44,7[illegible]6
Diameter, feet	420	220	396

5

BASELINE VEHICLE CONCEPT IDENTIFICATION AND DEFINITION

The baseline vehicle selected for definition is the short expendable (torus LO_2 tank) configuration shown in Figure 5-1.



(DESIGNED FOR 3 g IN SHUTTLE).

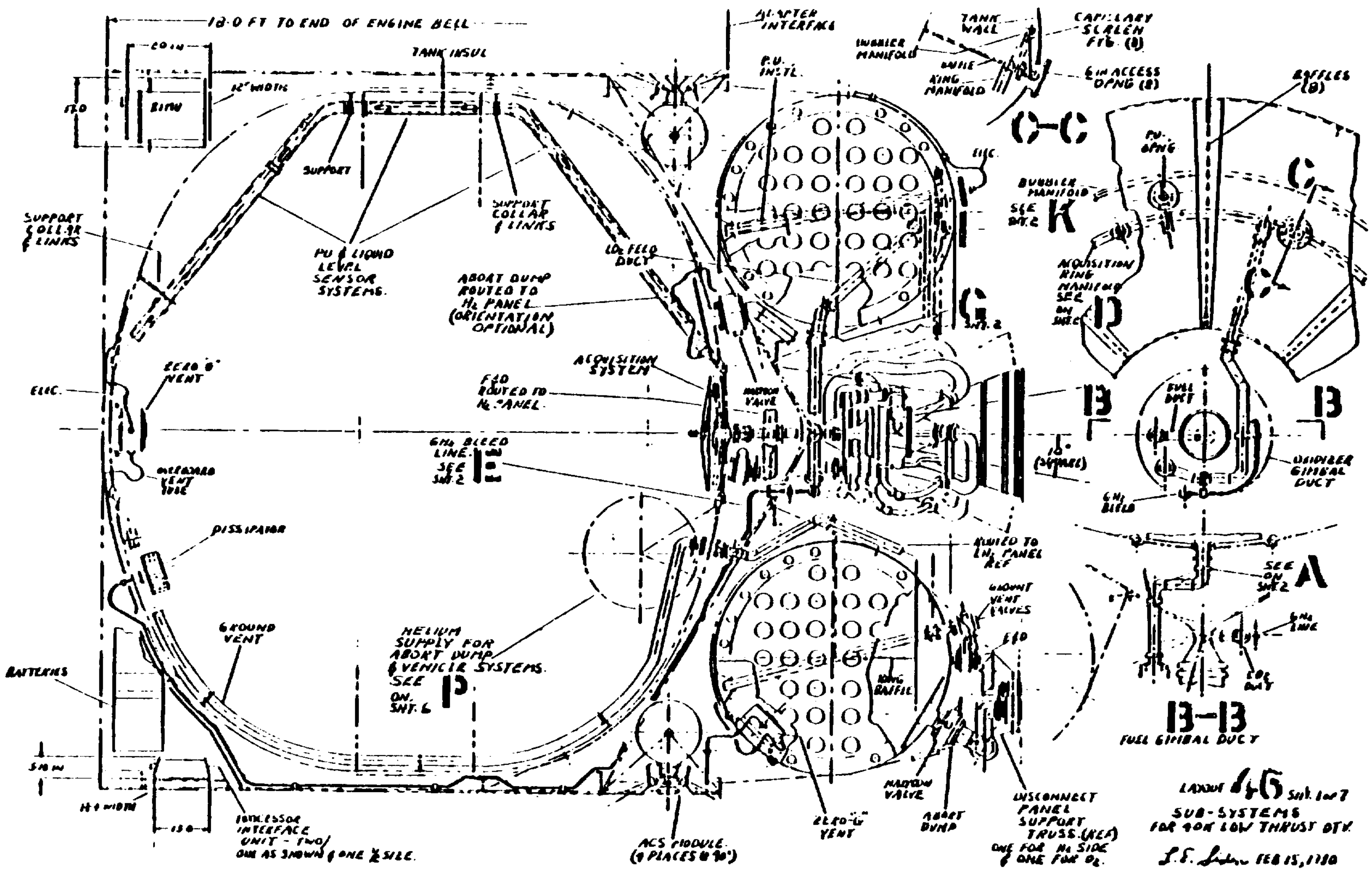
EXPENDABLE LOW THRUST OTV
(38K PROPELLANT @ MR = 6)

- PUMP FED 1.5K ENGINE
  - ENGINE MOUNTED/DRIVEN PUMPS (NO VEHICLE - MOUNTED BOOST PUMPS)
  - 16 PSIA MIN INLET PRESSURE
  - NPSH
    - LO_2 - 1 PSI
    - LH_2 - 0.5 PSI
  - AUTOGENOUS H_2 BLEED
- COMPOSITE STRUCTURE
- ALUMINUM TANKS
- PROPELLANT ACQUISITION
  - PARTIAL SETTLING
  - SCREENS
- MLI TANK INSULATION (15 LAYERS)
- PRESSURIZATION
  - HELIUM PRE PRESS. O_2 RUN
  - AUTOGENOUS H_2 RUN
- ZERO G VENT/MIXER
- FILL AND DRAIN } THROUGH SIDES OF ORBITER
- 300 SEC ABORT DUMP } THROUGH SIDES OF ORBITER
- N_2H_4 ATTITUDE CONTROL
- FUEL CELL POWER (1 KW)
- MISSION
  - 40- HR ORBITER C/O
  - 24- HR TRANSFER
  - 9 BURNS
  - 5 HR BURN TIME

Figure 5-1. Baseline design definition.

5.1 BASELINE CONFIGURATION, DESCRIPTION, AND WEIGHT

Figure 5-2 shows the detail layout for a short (18-ft length) OTV using a conventional liquid hydrogen tank and a toroidal liquid oxygen tank. The RL10 engine (short-low thrust) was used for layout/interface definition since new low thrust engines are yet to be defined. Both tanks are suspended from an outer body structure. A separate conical thrust structure is located between the two tanks and intersects with the outer body with a kick ring. This thrust structure also provides a second support system for the toroidal tank at the inboard side. Figure 5-3 shows a model built to approximate scale. Figure 5-4 shows dimensional data. Table 5-1 gives a summary weight statement for the baseline low thrust OTV. Table 5-2 gives a detailed weight breakdown by subsystems. Table 5-3 gives a detailed summary of propellants and fluids.



NOTE: SHORT RL10 USED TO DEFINE INTERFACES

Figure 5-2. Baseline low thrust OTV.

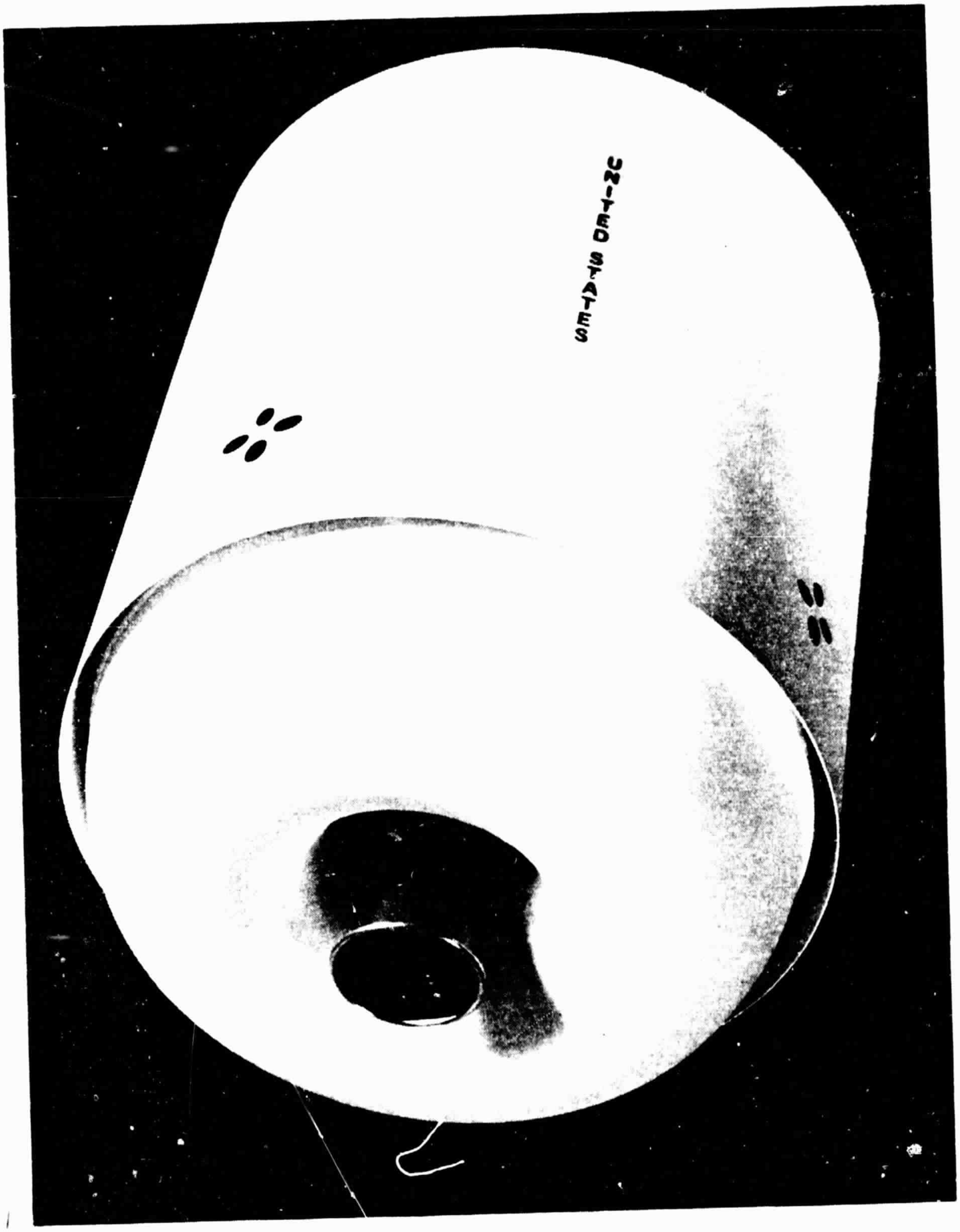


Figure 5-3. Low thrust OTV (model).

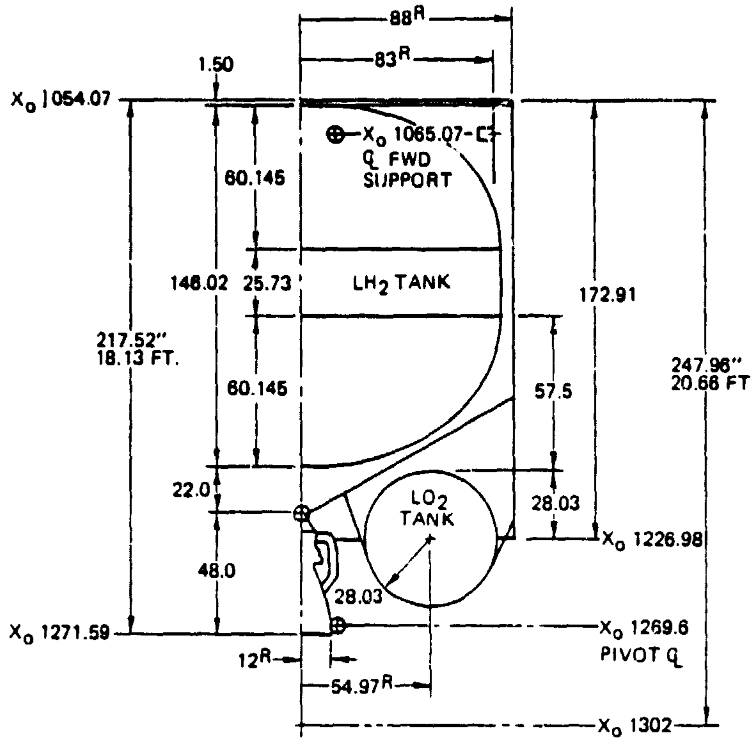
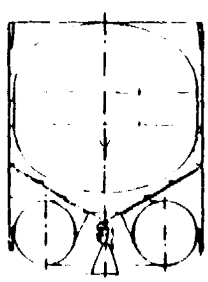


Figure 5-4. Low thrust OTV dimensions.

Table 5-1. Weight summary low thrust OTV.



WEIGHT DATA (LB)	
STRUCTURE	2,177
THERMAL CONTROL	635
MAIN PROPULSION	762
ATTITUDE CONTROL	206
AVIONICS	396
ELECTRICAL POWER	380
CONTINGENCY	668
TOTAL DRY WEIGHT	5,124
RESIDUALS	382
RESERVES	430
BURNOUT WEIGHT	5,936
INFLIGHT LOSSES	319
MAIN IMPULSE PROPELLANT	37,434
ACS PROPELLANT (INCL DISPOSAL ΔV)	551
STAGE TOTAL WEIGHT	44,240
PAYLOAD TO GEOSYNCHRONOUS ORBIT (MAX)	15,760
STAGE PLUS PAYLOAD WEIGHT	60,000
AIRBORNE SUPPORT EQUIPMENT	5,000
TOTAL LAUNCH WEIGHT	65,000
MASS FRACTION	0.856

Table 5-2. Detailed dry weight breakdown.

STRUCTURE	(2,177)
BODY STRUCTURE	815
FUEL TANK AND SUPPORTS	409
OXIDIZER TANK AND SUPPORTS	528
THRUST STRUCTURE	171
EQUIPMENT MOUNTING	40
PAYLOAD INTERFACE	63
DEPLOY ADAPTER INTERFACE	66
UMBILICAL PANEL	85
THERMAL CONTROL	(535)
FUEL TANK INSULATION	108
FUEL TANK PURGE ENCLOSURE	82
FUEL TANK PURGE SYSTEM	89
OXIDIZER TANK INSULATION	39
OXIDIZER TANK PURGE ENCLOSURE	59
OXIDIZER TANK PURGE SYSTEM	72
RADIATORS, ETC.	86
MAIN PROPULSION	(752)
MAIN ENGINE	100
THRUST VECTOR CONTROL	30
FEED SYSTEMS	90
FILL AND DRAIN SYSTEMS	64
GROUND VENT SYSTEMS	111
ZERO-G VENT SYSTEMS	41
ABORT DUMP SYSTEMS	136
PRESSURIZATION AND PURGE SYSTEMS	141
PROPELLANT MANAGEMENT	49
ATTITUDE CONTROL PROPULSION	(206)
THRUSTER MODULES	62
PROPELLANT TANKAGE	80
PROPELLANT FEED AND FILL	49
PRESSURIZATION AND PURGE	SEE MAIN PROP
PLUME IMPINGEMENT, ETC.	15
AVIONICS	(396)
ACS SENSORS AND ELECTRONICS	88
TELEMETRY, TRACKING AND COMMUNICATIONS	45
GUIDANCE	39
CENTRAL PROCESSING	45
RENDEZVOUS AND DOCKING	0
SERVO ELECTRONICS	30
SEQUENCE AND PYRO CONTROL	101
INSTRUMENTATION	48
ELECTRICAL POWER SYSTEM	(380)
FUEL CELL	159
FUEL CELL INSTALLATION	60
BATTERY	31
BATTERY INSTALLATION	5
INVERTER – BOOST PUMP	0
POWER CONTROL UNIT	15
BUS INTERFACE UNITS	10
HARNESS AND CONNECTORS	100
SUBTOTAL	4,456
CONTINGENCY	668
TOTAL DRY WEIGHT	5,124

Table 5-3. Detailed weight breakdown of propellants and fluids.

TOTAL DRY WEIGHT – BROUGHT FORWARD	5,124
RESIDUALS	(382)
TRAPPED LH_2/LO_2	142
TRAPPED GH_2/GO_2	226
TRAPPED N_2H_4	6
TRAPPED HELIUM	2
TRAPPED H_2O	3
TRAPPED N_2	3
BURNOUT WEIGHT WITHOUT FPR	5,506
RESERVES (2% ΔV FPR LH_2/LO_2)	430
BURNOUT WEIGHT WITH FPR	5,936
INFLIGHT LOSSES	(319)
ME START/STOP	135
ME LEAKAGE	8
BOILOFF GH_2/GO_2	133
HELIUM LOSSES	3
FUEL CELL H_2/O_2	40
IMPULSE PROPELLANTS	
ME LH_2/LO_2	37,434
ACS N_2H_4	551
STAGE TOTAL WEIGHT	44,240
PAYLOAD TO GEOSYNC. (MAX.)	15,760
STAGE PLUS PAYLOAD WEIGHT	60,000
AIRBORNE SUPPORT EQUIPMENT	5,000
TOTAL LAUNCH WEIGHT IN ORBITER	65,000

5.2 SUBSYSTEMS

5.2.1 TORUS LO_2 TANK. A design for a 468-ft^3 conventional toroidal tank for LO_2 service is shown in Figure 5-5 (Layout 59). The tank features a structural arrangement which permits access to the interior and provisions for a low conductive support system located at the inside and outside diameters. Also included is an acquisition system, a pressurization bubbler manifold, a ground vent duct, a fill and drain port, abort dump sump, a ring baffle, and a boss for an electrical penetration fitting. Internal bracketry is also provided for mounting a zero-g vent apparatus, a propellant utilization system, and electrical harnessing.

5.2.1.1 Structure. Design approaches for the torus tank are shown in Figures 5-6 through 5-10.

The primary structural members are eight rings equally spaced at 45°, and eight shell segments. The rings also serve as radial baffles and have a tee cross section. The 24-inch inside diameter was chosen for accessibility between compartments and the webs are perforated with holes. Tests will be required to determine any effects the 24-inch access holes may have on the baffling characteristics. If required, removable perforated doors may be added to each ring.

The flange ends are step machined to fit the weld zones on the shell segments.

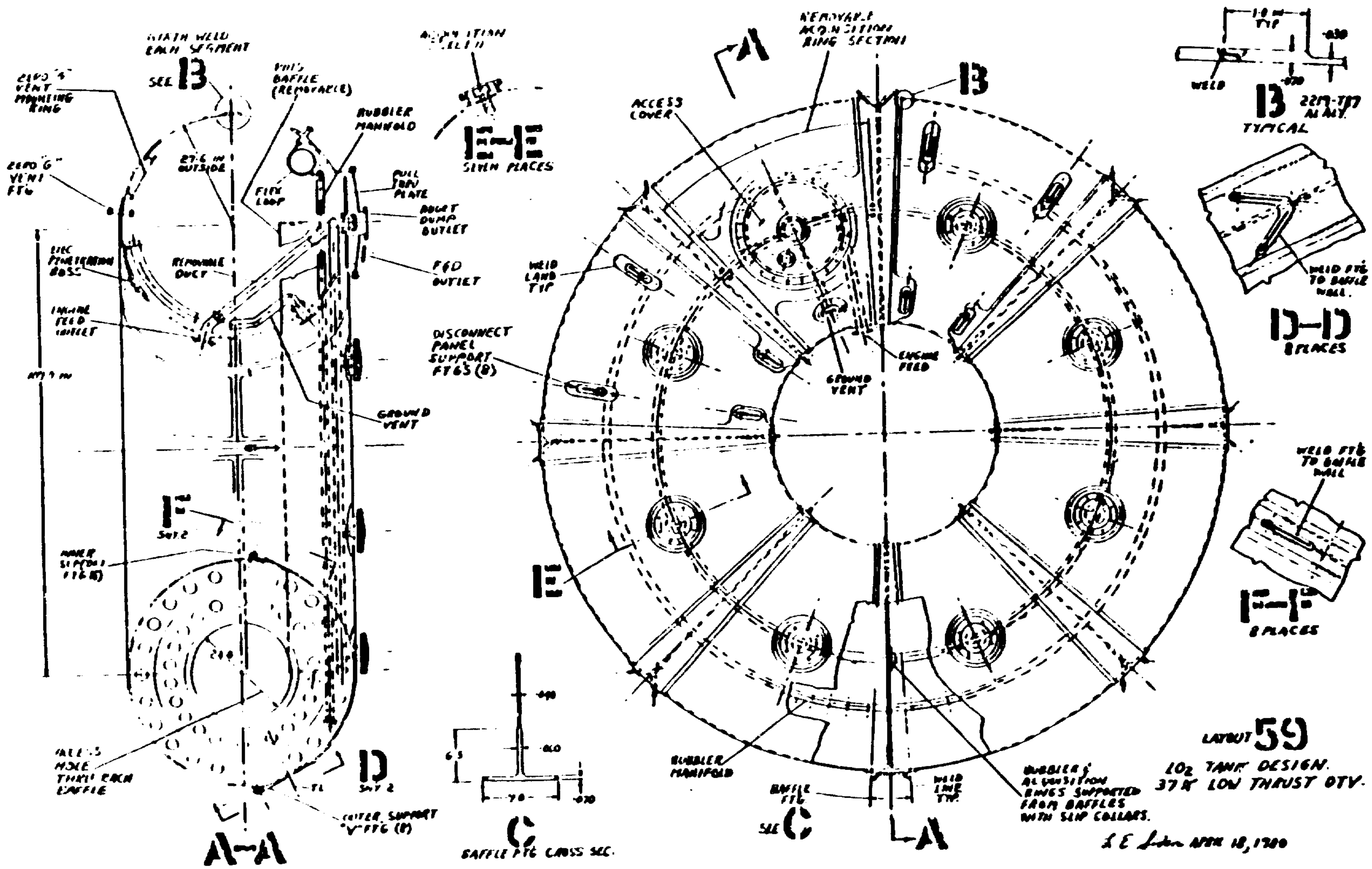


Figure 5-5. Torus LO_2 tank design.

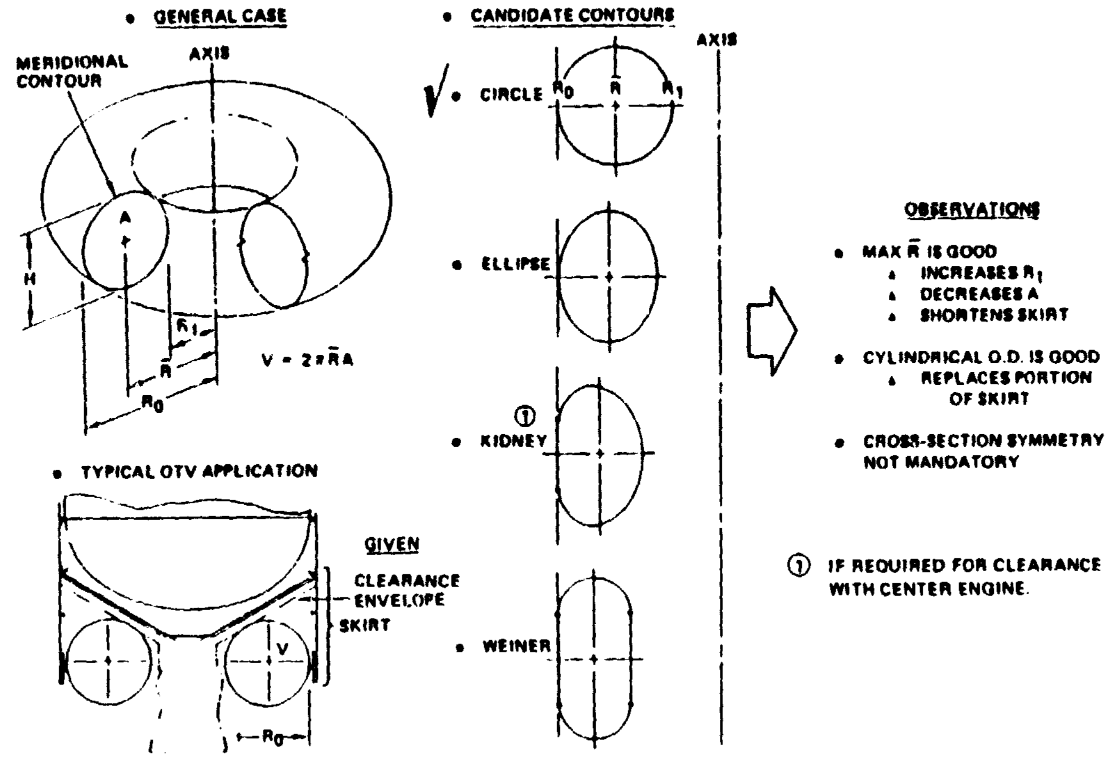
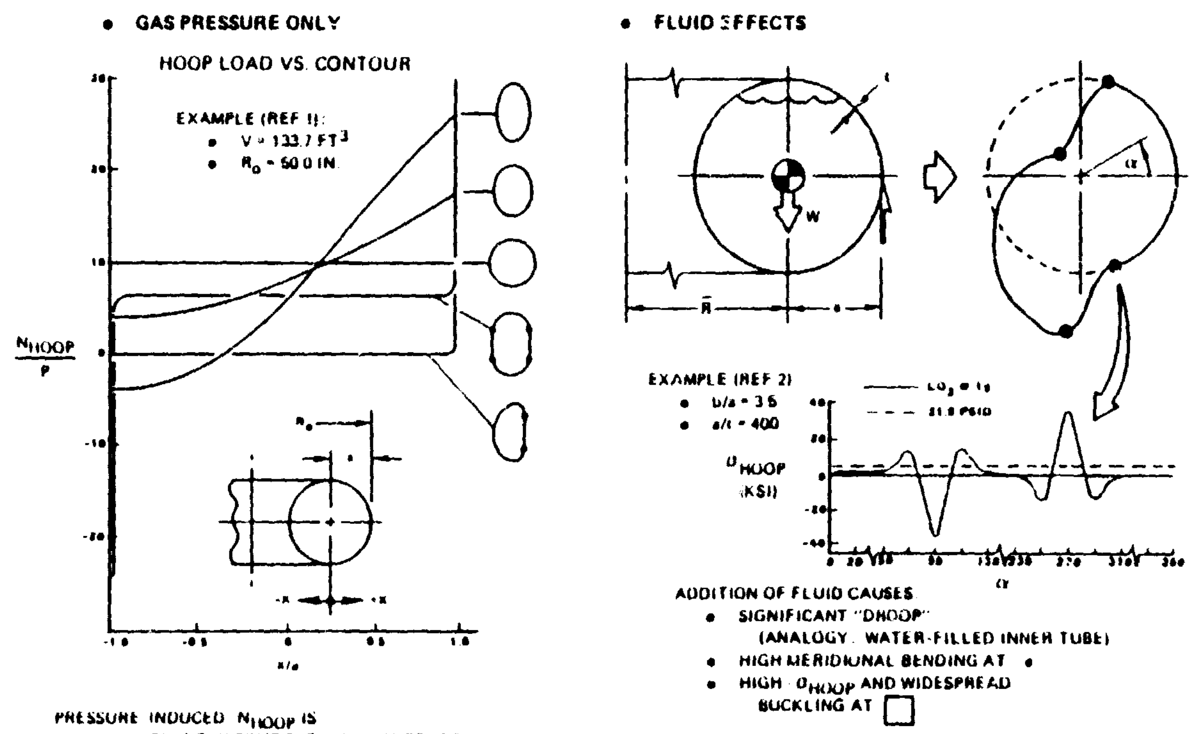


Figure 5-6. Torus tank considerations - I. Geometry.



PRESSURE INDUCED N_{HOOP} IS
- INHERENT IN SOME SLENDER CONTOURS
- VERY HIGH IF INNER SURFACE IS SINGLY CURVED
- AVOIDABLE BY MERIDIONAL TAILORING

References

1. Turner, H.M., Design Parameters for Elliptical Toroidal Pressure Vessels, Aerospace Engineering, November 1962
2. Spier, E.E., et al, Linear Bending Analysis of a Thin Toroidal Propellant Tank, J. Spacecraft & Rockets, May 1966

Figure 5-7. Torus tank considerations - II. Membrane behavior.

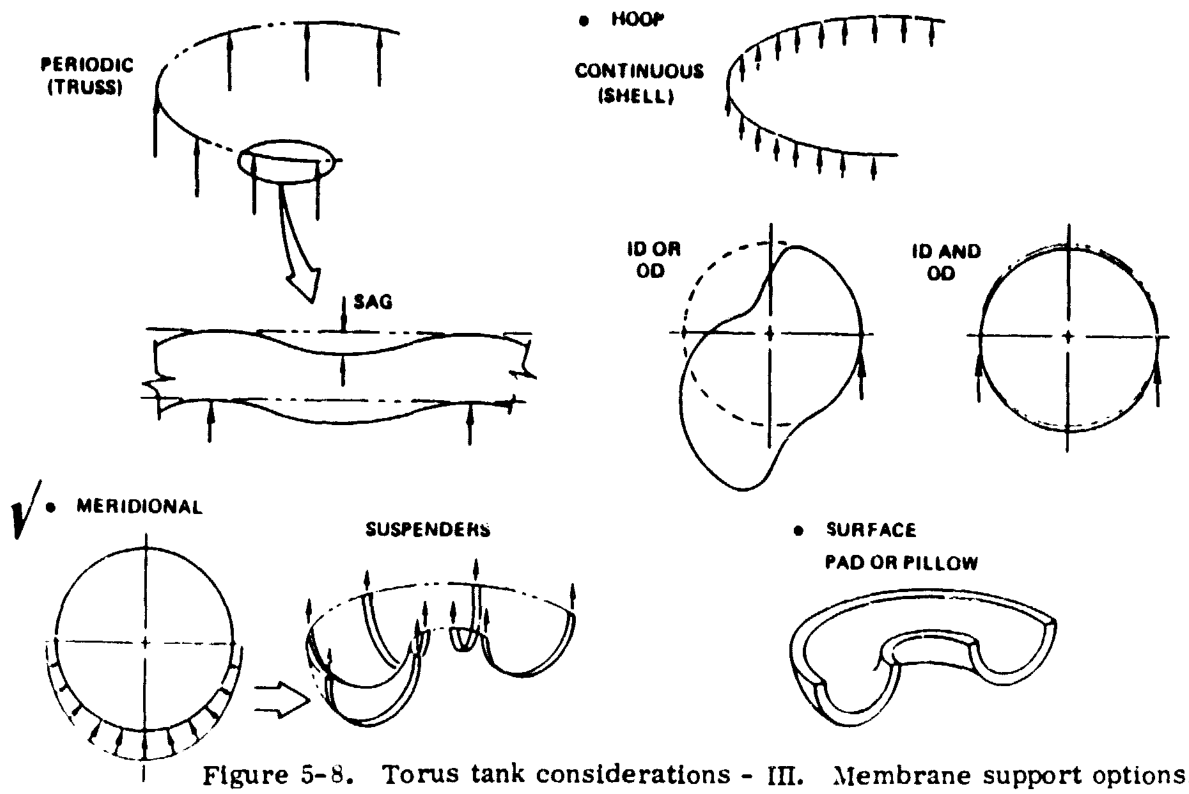


Figure 5-8. Torus tank considerations - III. Membrane support options.

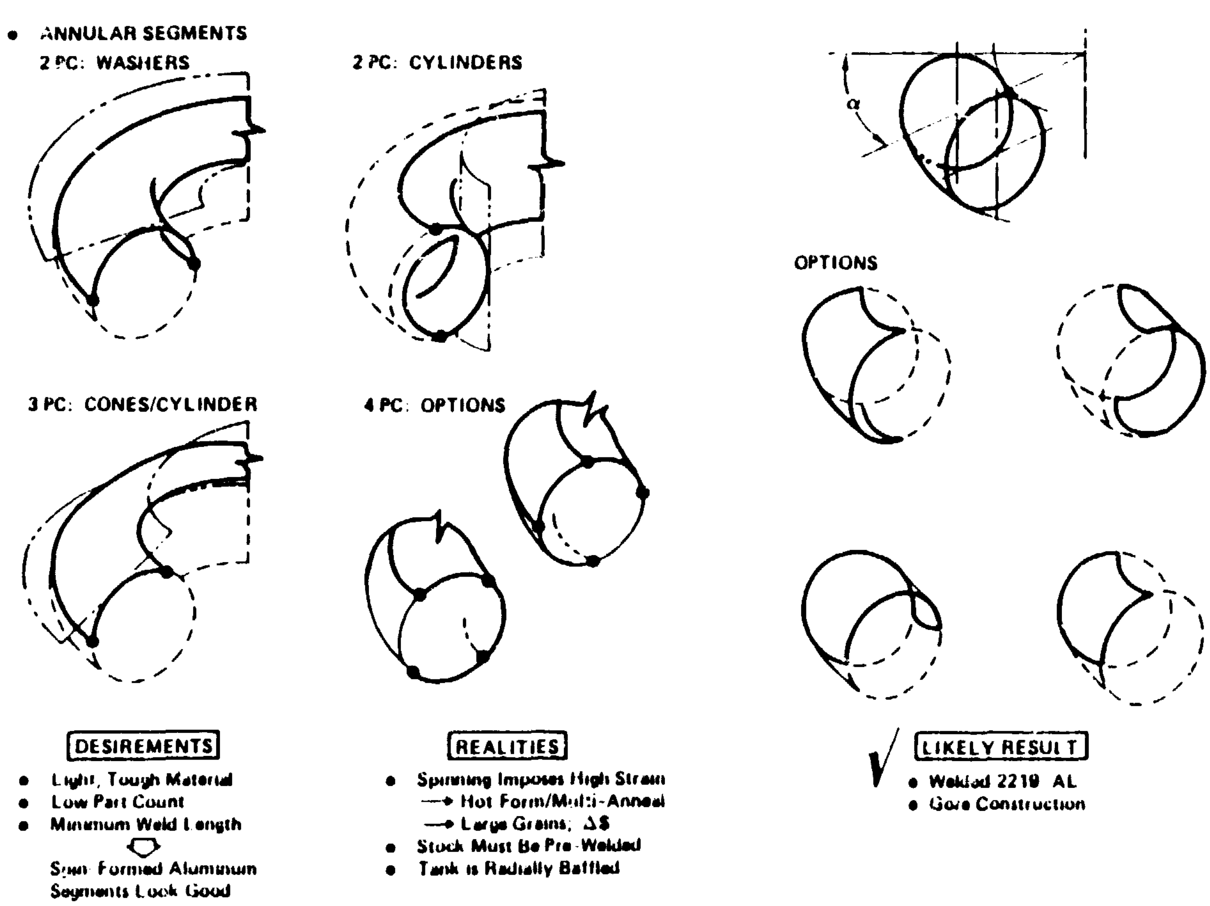


Figure 5-9. Torus tank considerations - IV. Membrane forming and joining.

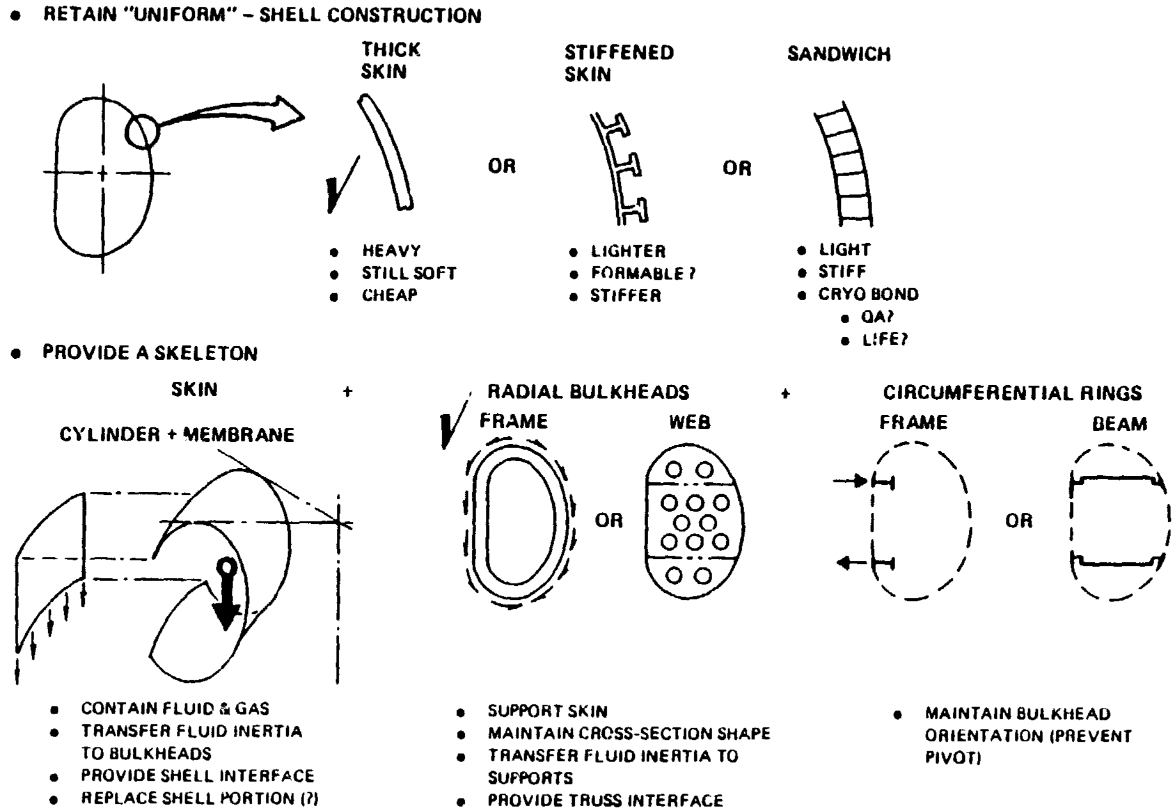


Figure 5-10. Torus tank considerations - V. Structural concept options.

Each of the eight shell segments consists of two 180° sections welded at the girth. Each segment also has weld lands for wall penetrations and for the disconnect panel support fittings. The largest penetration is the 24-inch access opening. This access opening plus five additional penetration fittings are located in one shell segment. This arrangement allows ready access to most of the system components without entering adjacent compartments. The access opening door also contains two outlets and sumping equipment for abort dump, fill, and drain. Each of the remaining seven shell segments has one hand hole for penetration which serves the acquisition system. In addition to the hand holes, two of the segments have weld lands for the disconnect panel support fittings.

After installation of the penetration fittings, the shell segments are fitted to ur rings and held in place by fixtures. To allow for tolerances, the weld land widths on one segment are made oversize so that trimming can be performed. The complete assembly is then welded.

The tank is supported at the outside diameter with eight pairs of low conductive struts arranged in a "V" pattern and oriented so that the line of actions are tangent to the tank wall. Additional support is provided at the inside diameter with eight single struts which are also arranged so that the reaction loads are directly tangentially to the shell. To accommodate this support system, 16 fittings are welded to the rings.

5.2.1.2 Internal Structure

a. Pressurization Bubbler Manifold. The bubbler manifold is a 133-inch diameter tubular ring located forward of the acquisition system. The manifold has a series of holes equally spaced over the entire length and is supported from the ring baffles with slip collars. Helium gas is supplied through a tank wall penetration fitting which is connected to the manifold with a tubular flex loop.

b. Ground Vent Duct. A tank wall penetration fitting located adjacent to the access opening serves as the ground vent outlet. This fitting is attached to an internal duct which follows the tank wall contour and routes forward to the ullage area. The forward end is radially restrained only with a collar fitting.

c. Fill and Drain Provisions. The tank is filled or drained through a flange penetration fitting located in the access door.

d. Abort Dump Provisions. The abort dump circuit is separate from the fill and drain; therefore, a flanged opening is provided at the center of the access door. A pull-through plate mounted on two cross webs is attached on the inside of the access door. A hole at the center of this pull-through plate allows the acquisition system capillary device to be located inside the sump.

e. Ring Baffle. A 109-inch diameter × 10-inch width ring baffle is provided at the tank center. The baffle is constructed in eight 45° sections and is attached to the radial baffles with angle clips. Each section is aluminum alloy sheet with stiffener beads.

f. Electrical Penetrations. Internal wiring is required for the zero-g vent, PU system, and instrumentation. The tank wall is equipped with a boss-type penetration fitting which interfaces with a removable receptacle. The receptacle is sealed to this boss with a metal radial seating seal using a backup flange.

g. Internal Bracketry. Internal bracketry is required for mounting the zero-g vent apparatus, vent duct support, the PU assembly, and wiring harnesses. This bracketry consists of small z-rings, tee fittings, angles, and collars. The tank shell incorporates weld lands for each bracket which, in turn, are fillet welded to the tank wall.

h. Seals. All flange-type connections have metal radial seating primary seals and secondary metal O-ring seals. The cavities between these seals are vented overboard through a tubular manifold. A reduction in the number of mechanical connections is possible by replacing the flanged covers on the hand holes with welded caps. The use of welded caps, however, requires installing or replacing the acquisition capillary devices from the inside of the tank. For small tank wall penetrations requiring tube connections, induction brazing or orbit arc welding will be used.

For connections inside the tank, AFRPL connectors using bobbin seals are employed for the helium feed tube running from the tank wall penetration fitting to the bubbler manifold. V-band connectors using metal seals are used for the larger lines. Some typical examples are the vent duct, and the removable section for the acquisition ring. Both the bubbler and acquisition manifold will have to be installed in sections. Where possible, the joints between sections will be orbit arc welded.

5.2.2 PROPELLANT ACQUISITION. Propellant acquisition systems were defined for use with a 1000-lb thrust LH_2/LO_2 engine. System selection was made after evaluation of feasibility and weight penalty for several propellant management techniques.

5.2.2.1 Propellant Acquisition Concepts. A propellant acquisition system operates by providing subcooled propellants to the main engine feed system pumps prior to each main engine start, and during main engine firing to prevent pump cavitation. This liquid can be supplied through either of two approaches. The most developed approach is to use settling motors for collecting propellant over the tank outlet prior to each engine start. The other approach is to use screens or capillary devices for maintaining liquid over the outlet during the entire vehicle mission. Capillary acquisition devices are divided into two general areas: (1) partial acquisition devices (start baskets) which do not contact the liquid pool during a coast but contain enough liquid propellant to start the engine and settle out the remaining propellant and (2) total acquisition devices which maintain contact with the liquid pool at all times.

The mission considered in the acquisition system design was an eight-burn transfer from LEO to GEO with rather long coast durations between burns. Two characteristics of this mission that differentiate the acquisition system design from previous studies are the low vehicle acceleration levels of 0.02 to 0.05 g and the possibility of a thrust vector misalignment caused by payload flexibility at final main engine cutoff (MECO). The influence of these factors is dependent upon the particular propellant management technique under consideration.

a. Total Capillary Acquisition. During the coast periods, propellant may migrate toward the forward end of the tank due to vehicle drag. In order for a total capillary acquisition device to maintain contact with the liquid pool at all times, it must extend throughout much of the tank. The resulting rather severe weight penalty of this system does not make it competitive with either of the two other acquisition methods for this mission. Therefore, it was eliminated from further consideration.

b. Propulsive Settling. This approach uses a propulsive system to provide low acceleration for propellant collection following each coast period, prior to main engine operation. Consequently, the system weight penalty is proportional to the number of burns during a mission. Propulsive settling does not provide a means for acquiring the propellants for the case of a thrust misalignment during the final stages of draining. Additionally, because of the low acceleration environment of the OTV, rather severe suction dip of the propellants can occur during final draining resulting in vapor ingestion at relatively high propellant levels. Both may result in rather large propellant residuals at MECO.

c. Partial Capillary Acquisition. Partial acquisition devices, or start baskets, function by maintaining wetted screen barriers over the tank outlet. The start basket is sized to retain propellant in sufficient quantity during a vehicle coast to accommodate engine startup, propellant settling, and basket refill without supplying vapor to the engine feed line. Vapor will enter the start basket during a coast if heat input results in evaporation of some of the liquid. Vapor will also enter during engine startup as liquid is drawn from the basket before the propellant has been settled. Most of this vapor is then expelled from the start basket during the refilling operation under high acceleration. The amount of vapor which remains in the start basket depends on the screen surface retention pressure which must be overcome before vapor can penetrate the wetted screen. The final vapor head trapped inside of the start basket is equal to:

$$H_V = \frac{4\sigma}{\rho_L g \; D_{BP}}$$

where: H_V = trapped vapor head
σ = surface tension of the propellant
ρ_L = liquid propellant density
g = acceleration in g's
D_{BP} = screen bubble point

In previous partial acquisition device studies (References 10 and 11, the trapped vapor head presented only a minor problem for the 0.1 to 1 g acceleration range. This problem was alleviated through the use of a screened stand pipe placed at the top of the capillary device. The stand pipe is constructed of

screen having a higher bubble point diameter and, therefore, lower surface tension pressure than the remainder of the basket, thereby reducing the trapped vapor head. However, the 0.02 to 0.05 g acceleration range under consideration in this study yields a high trapped vapor head no matter which screen is selected for use with the acquisition device. This can be seen from Figures 5-11 and 5-12 which show trapped vapor head plotted versus acceleration for various screen meshes. With no practical means available to eliminate the trapped vapor head from the start basket, for low thrust vehicle missions, vapor penetration must be totally eliminated or minimized as much as possible. This makes the low thrust start basket design significantly different from previous start baskets designed for higher acceleration environments.

The weight penalty for a partial capillary acquisition device is relatively insensitive to the number of burns in a mission. It, therefore, becomes a more attractive system as the number of burns increase. Additionally, the system may be designed to acquire the propellants during a thrust misalignment, which a propulsive settling system is unable to do. Finally, suction dip of the propellants does not present a large problem since vapor ingestion will not occur until the surface retention pressure of the screen is exceeded, which will occur at low propellant levels.

5.2.2.2 System Selection. Because neither of the propellant management systems is without problems, it was decided to use the attributes of each system to design a combined propulsive settling-partial capillary acquisition system. This system uses propulsive settling to initiate propellant acquisition for main engine start; however, by placing a system of screened channels at the bottom of the tank it is no longer necessary to have the propellants completely settled before main engine start can occur. As long as part of the screened device is in contact with the liquid pool, vapor will not be drawn into the acquisition device. The system also provides a means of acquiring propellants during thrust misalignment and minimizes the problems associated with suction dip of the propellants.

5.2.2.3 Torus Tank Acquisition Device. The acquisition device for the toroidal LO_2 tank consists of a ring manifold located at the bottom of the LO_2 tank with eight equally spaced screened branch channels (Figure 5-13), which supplies a single outlet to the engine. This device is based on a concept previously tested by GDC. No matter what orientation the thrust offset, liquid is supplied and residuals are greatly reduced. (See Figure 5-14.) This design eliminates the complication of multiple outlets/sumps. Complete thermal isolation ensures liquid at all times. Design details are shown in Figure 5-15, and further described in the following paragraphs.

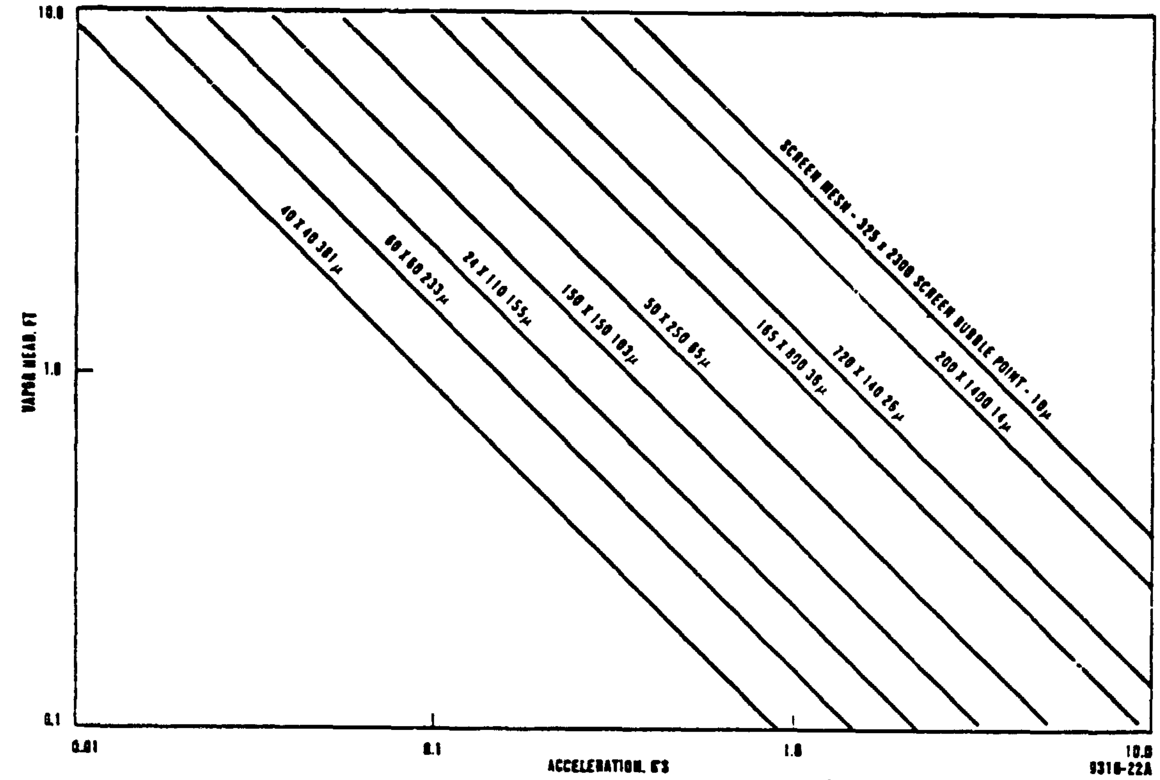


Figure 5-11. LH_2 trapped vapor head vs. acceleration for various screens.

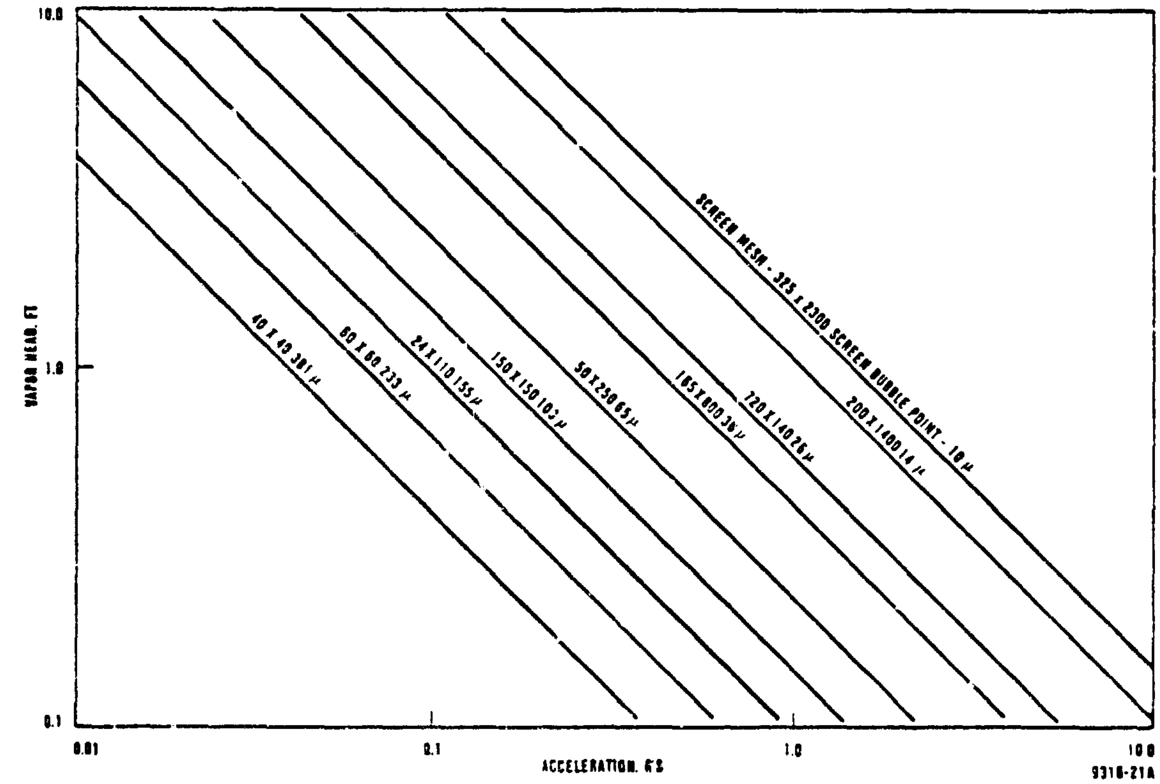


Figure 5-12. LO_2 trapped vapor head vs. acceleration for various screens.

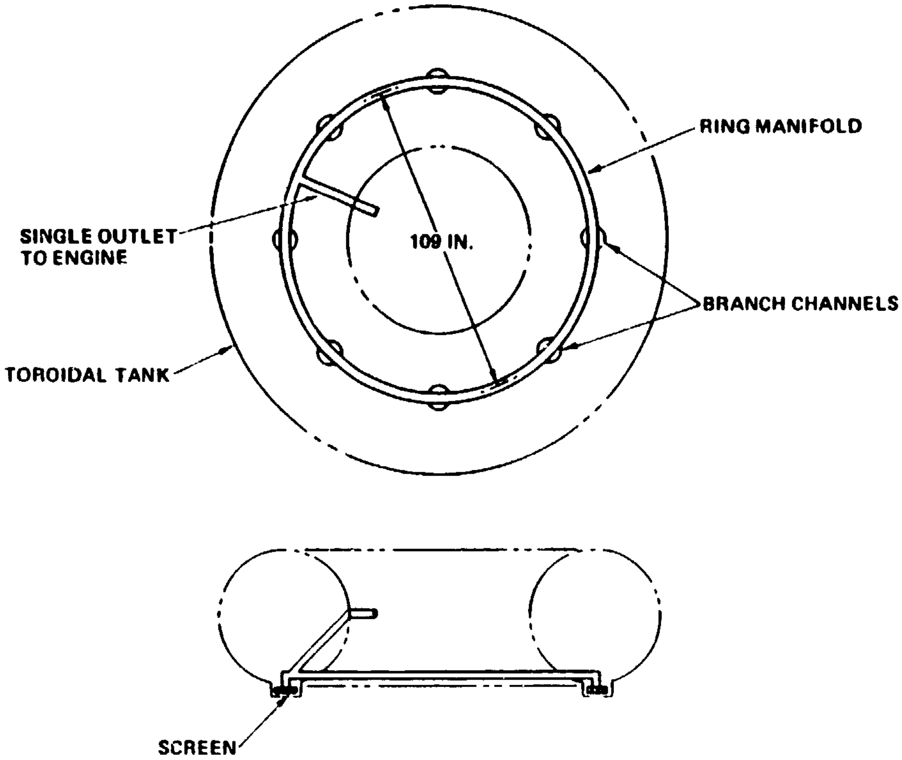


Figure 5-13. LO_2 tank propellant acquisition device.

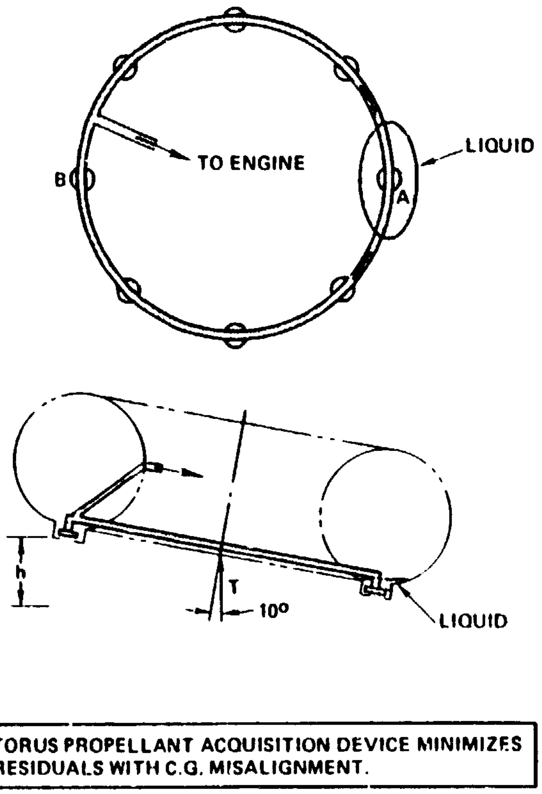


Figure 5-14. LO_2 acquisition with thrust misalignment.

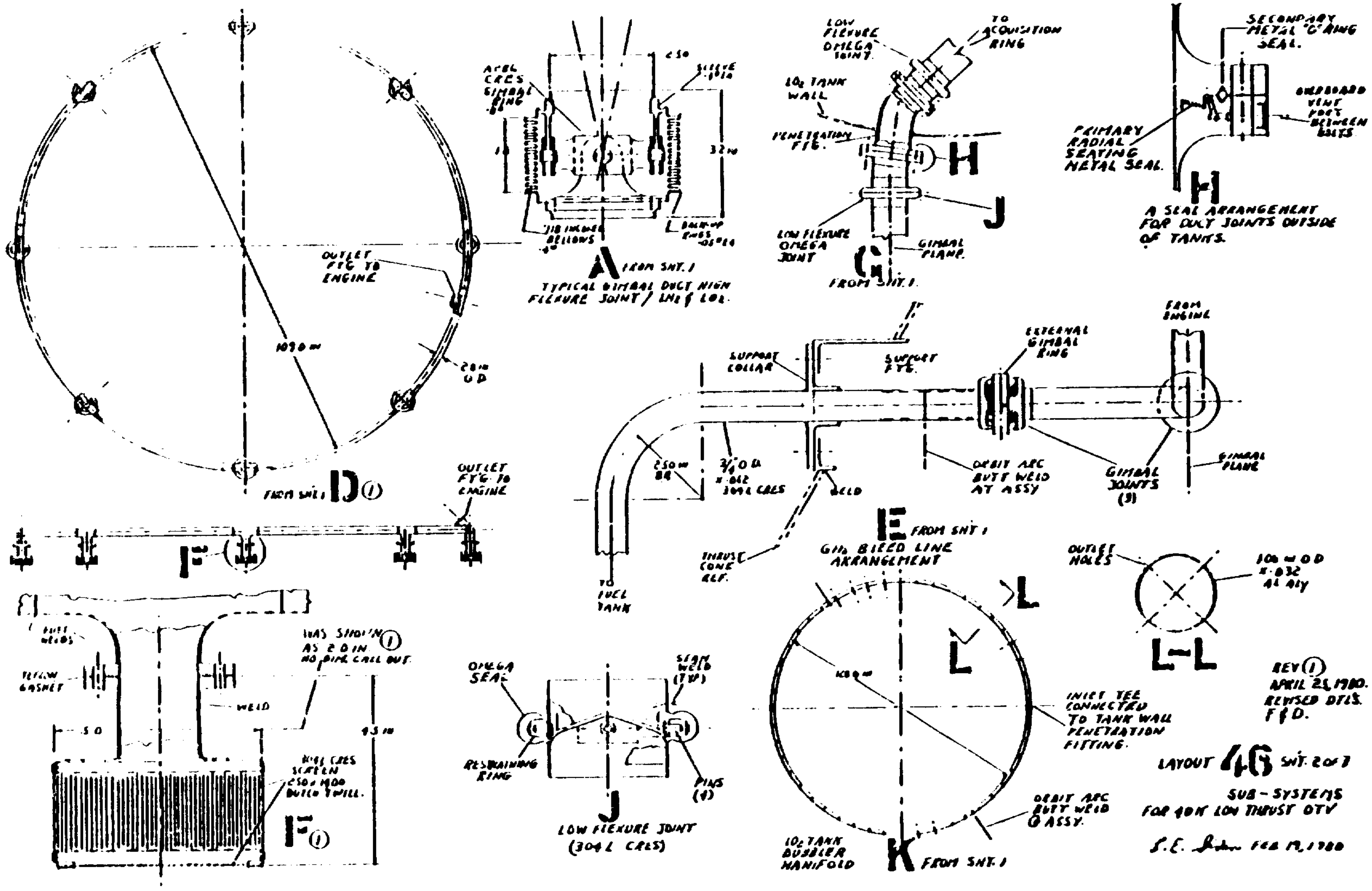


Figure 5-15. Torus acquisition device design.

a. Acquisition System. The acquisition system is a 109-inch diameter tubular ring manifold with nine tee fittings, eight capillary devices, and an outlet duct. The ring is located at the tank center and oriented so that eight tee fittings are opposite the tank access door and hand holes. The ring is supported with eight slip collars which are attached to the web sections of the ring baffles. A 30-inch removable section is provided at the access door to permit entry to the tank interior. Each of the eight tee fittings has a flanged side outlet which is attached to a capillary device. These capillary devices are 4-inch diameter × 2-inch long cylindrical screen assemblies with a flange at one end. The devices are installed from the outside of the tank through the hand holes. An alternative method would permit installation from inside the tank, which would delete the need for seals at the hand holes. When installed, the capillary devices protrude into the full depth of the hand holes.

The outlet for the manifold is the ninth tee fitting located adjacent to the access opening. This tee fitting is connected to a tank wall penetration fitting with a removable CRES duct equipped with flex joints for absorbing tolerances and flexures.

b. LO_2 Acquisition Device Sizing. The LO_2 tank acquisition device was sized for a worst case condition at the end of the last burn when a thrust misalignment of 10° might position the propellant in contact with only the branch channel located farthest from the tank outlet. The requirement to prevent vapor ingestion during main engine firing under this condition is that the system flow losses not exceed the surface retention pressure of any of the screened branch channels. That is

$$\Delta P_\sigma > \Delta P_b + \Delta P_r + \Delta P_h + \Delta P_s \tag{5-1}$$

$$\Delta P_\sigma,\ \text{screen retention pressure} = \frac{\phi\sigma}{D_{BP}} \quad . \tag{5-2}$$

where ϕ = a dimensionless constant dependent on the individual screen and fluid being used

σ = the surface tension

D_{BP} = the screen bubble point diameter

ΔP_b = the pressure loss due to bending from the branch channel into the ring manifold $= \dfrac{K_b\ \rho_L V^2}{2}$ (5-3)

where K_b = a pressure loss coefficient taken from Reference 12

ρ_L = the fluid density

V = the branch channel fluid velocity

ΔP_r = the pressure loss due to flow in the ring manifold $= \dfrac{K_r\ \rho_L V^2}{2}$ (5-4)

where K_r = a pressure loss coefficient accounting for both friction and bending in the manifold taken from Reference 13.

ΔP_h = the hydrostatic pressure difference between branch channels $= \dfrac{\rho g h}{gc}$ (5-5)

where g = acceleration

h = the differential head supported by the screen

gc = a dimensional constant

ΔP_s = the screen pressure loss $= \dfrac{\mu L \rho LH_2\, AV + \rho_L\, BV^2}{\mu LH_2}$ (5-6)

where μ_L = the propellant viscosity

μLH_2 = the viscosity of 50 psi LH_2

ρLH_2 = the density of 50 psi LH_2

A&B = viscous and inertial constants determined in Reference 14.

The screens listed in Table 5-4 were initially considered for use in the acquisition system. They represent a broad sample of screen meshes available.

Table 5-4. Screen types.

Screen Mesh	Weave	Bubble Point Diameter, In. $\times 10^{-4}$
325 × 2300	Twilled Dutch	3.94
200 × 1400	Twilled Dutch	5.51
500 × 500	Twilled Square	10.00
720 × 140	Reverse Dutch	10.24
165 × 800	Twilled Dutch	14.17
50 × 250	Plain Dutch	25.59
150 × 150	Square	40.55
24 × 110	Plain Dutch	61.02
60 × 60	Square	91.73
40 × 40	Square	150.00

The surface retention pressure (ΔP_σ) of each of the screens is plotted versus screen bubble point diameter in Figure 5-16. It is obvious from the figure that the two finest screen meshes, the 325 × 2300 and the 200 × 1400, are far superior to any of the other screens in terms of retention capability. This is not the only criterion for selection, however. The flow pressure loss across the screen is also an important consideration and it generally increases as the surface retention pressure increases. Figure 5-17 shows screen flow pressure loss plotted against surface retention pressure for two different screen flow areas.

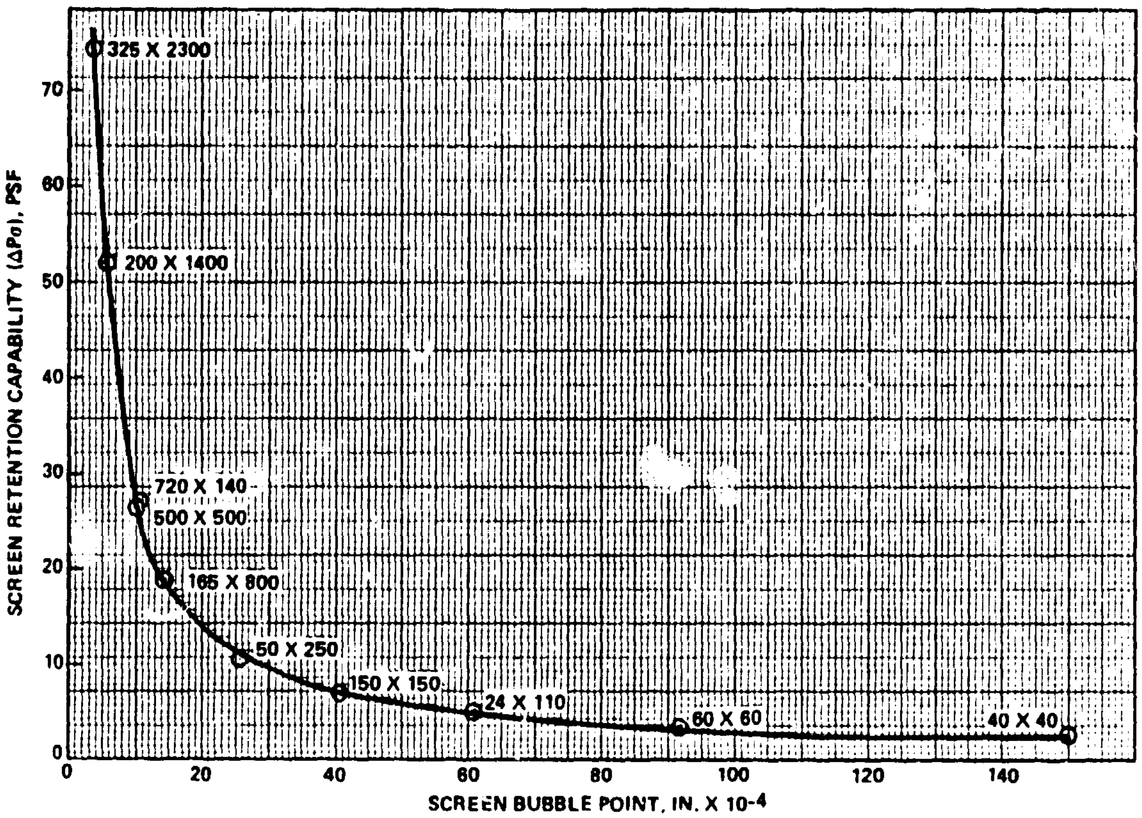


Figure 5-16. Screen surface retention pressure in 13 psi LO_2.

Looking at the pressure difference between the surface tension pressure and the screen flow pressure loss as the reserve retention pressure, the fine mesh screens offer a significant advantage over the coarse screens in terms of this reserve retention pressure at the hither screen flow area. It was for this reason that the candidate screen field was narrowed down to four screens. Those selected for further study were the 325 × 2300, 200 × 1400, 720 × 140, and 500 × 500 screens.

The ring manifold diameter was selected on the basis of pressure loss in the manifold. Figure 5-18 shows pressure drop in the ring manifold for flow from branch A (Figure 5-15) to the engine outlet for different manifold diameters. As can be seen from the figure, the pressure drop is extremely sensitive to the manifold diameter. The 1.5-inch diameter manifold was selected in order to keep the manifold pressure loss approximately an order of magnitude less than the screen retention pressure. A larger diameter manifold was not chosen as it would increase system weight and liquid residuals without any appreciable decrease in the manifold pressure loss.

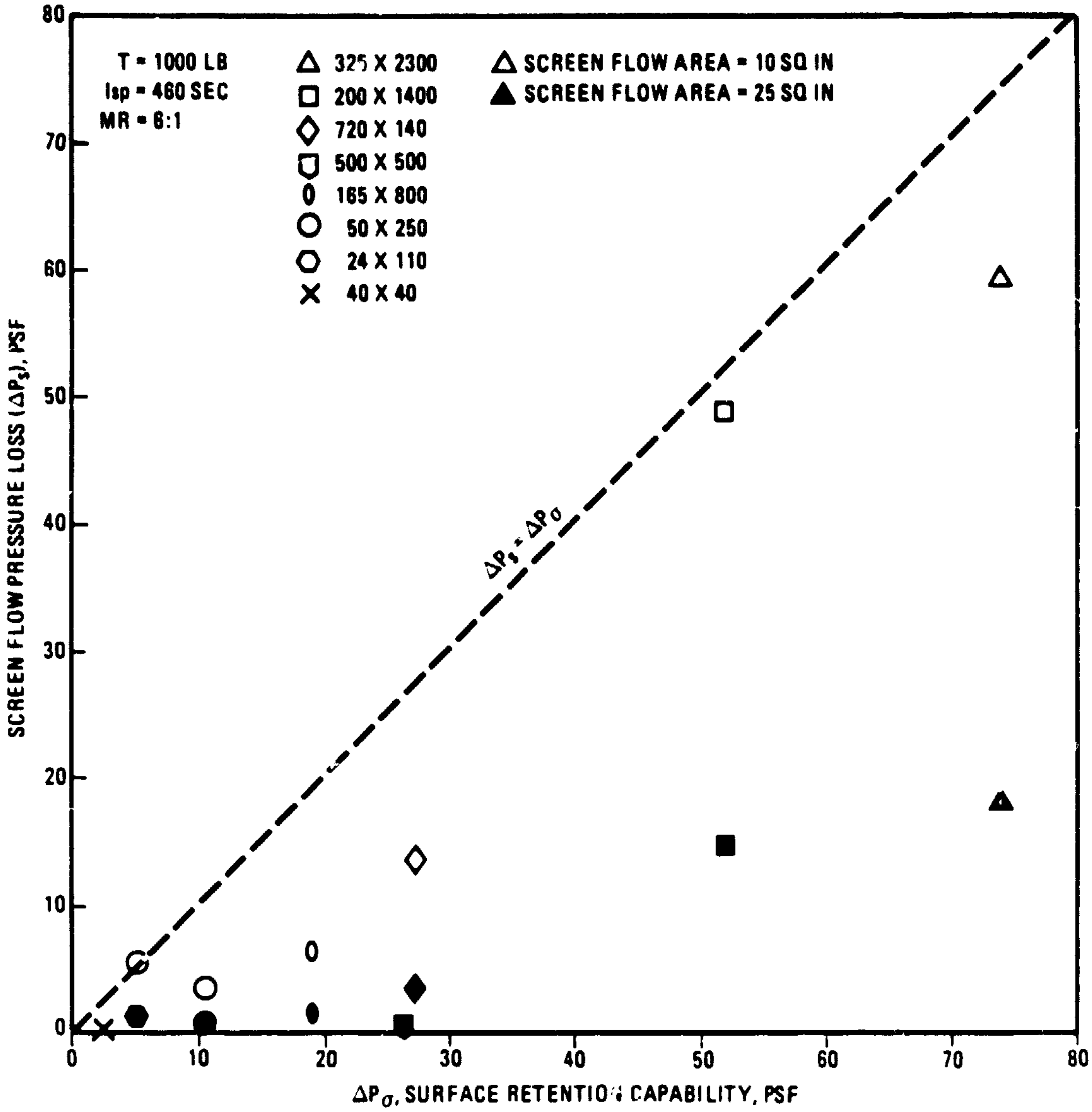


Figure 5-17. LO_2 screen flow pressure loss, $\dot{m}$ = 1.863 lb/sec.

Figure 5-19 shows the branch channel configuration. The side and bottom of the disk at the end of the channel are screened, with the screen mesh, disk height (h) and disk diameter (d) chosen to maximize screen retention capability while minimizing flow losses. The total system pressure loss between branch A and branch B was evaluated for the four screens and various combinations of d and h. Figure 5-20 shows data for the two most extreme screens in terms of system pressure drop as a percentage of surface retention pressure.

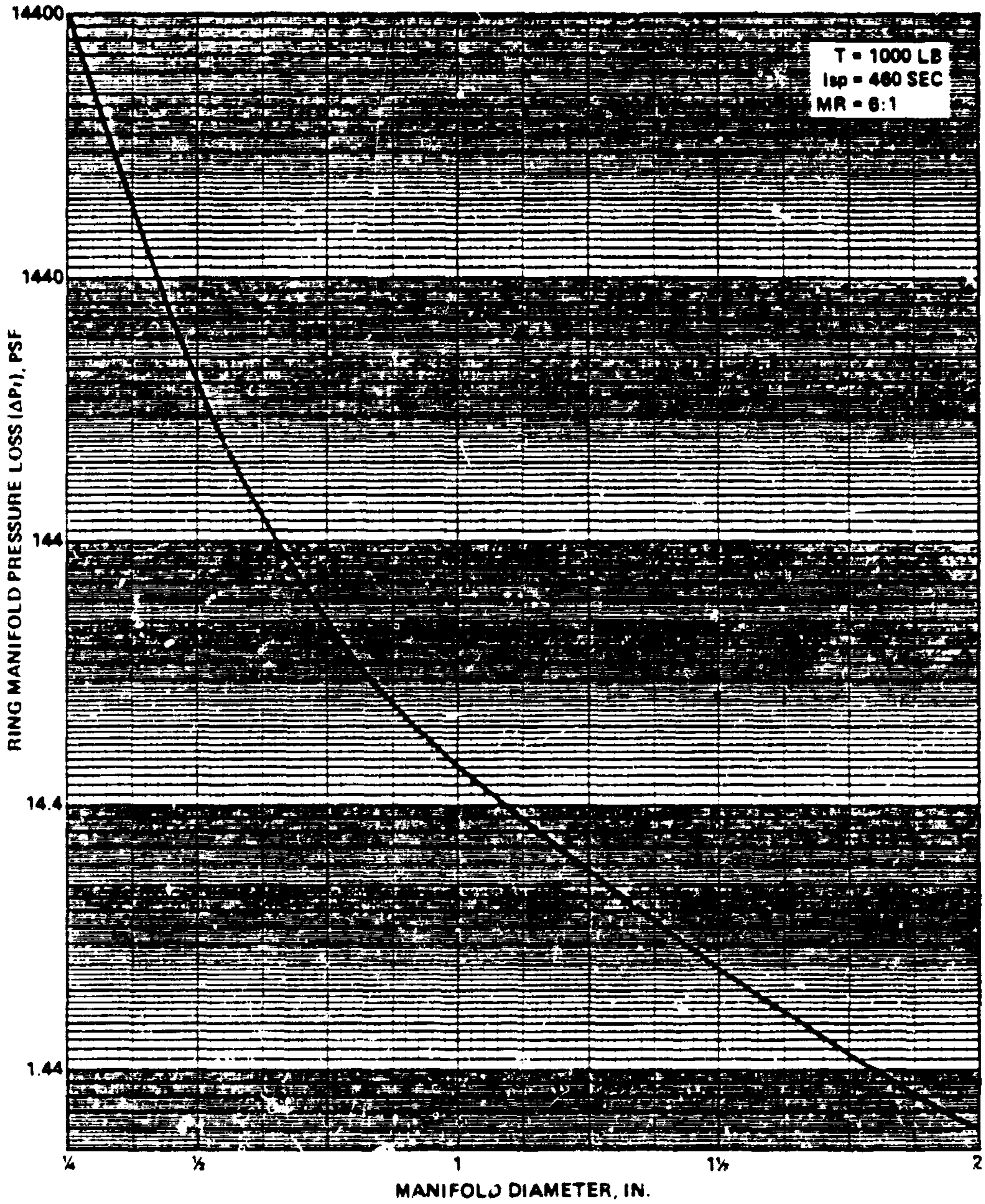


Figure 5-18. LO_2 tank acquisition system ring manifold pressure loss, $\dot{m}$ = 1.863 lb/sec.

Based on these data, the 325 × 2300 screen was selected for use with the 4-inch by 1-inch disk in order to retain a factor of safety of about 2 against vapor penetration. The surface retention pressure will be exceeded in the most severe case of flow through only one branch channel with this branch channel selection only when the side of the disk is completely uncovered, greatly reducing tank residuals.

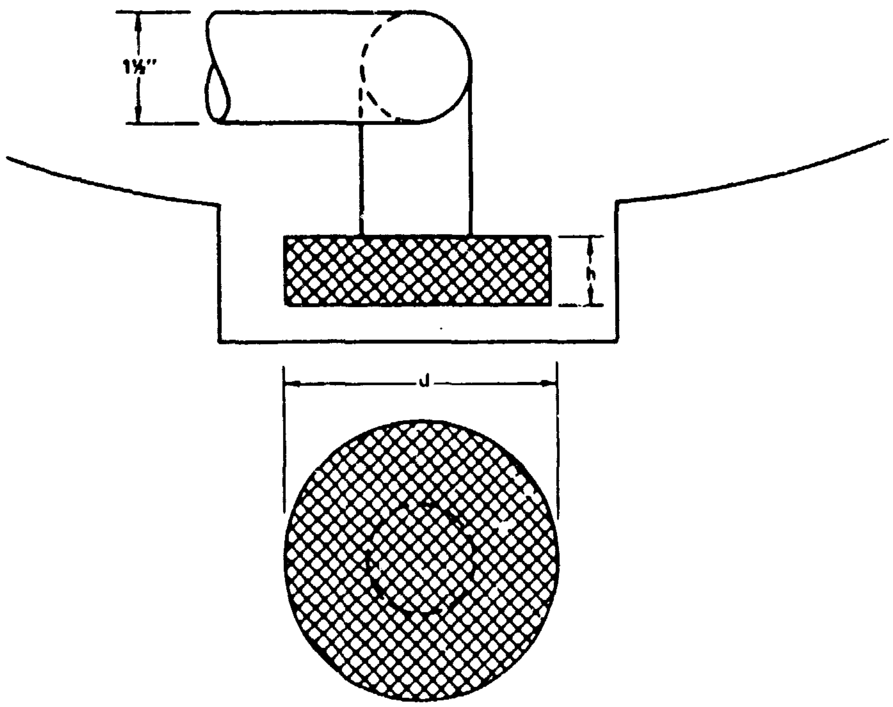


Figure 5-19. Branch channel configuration.

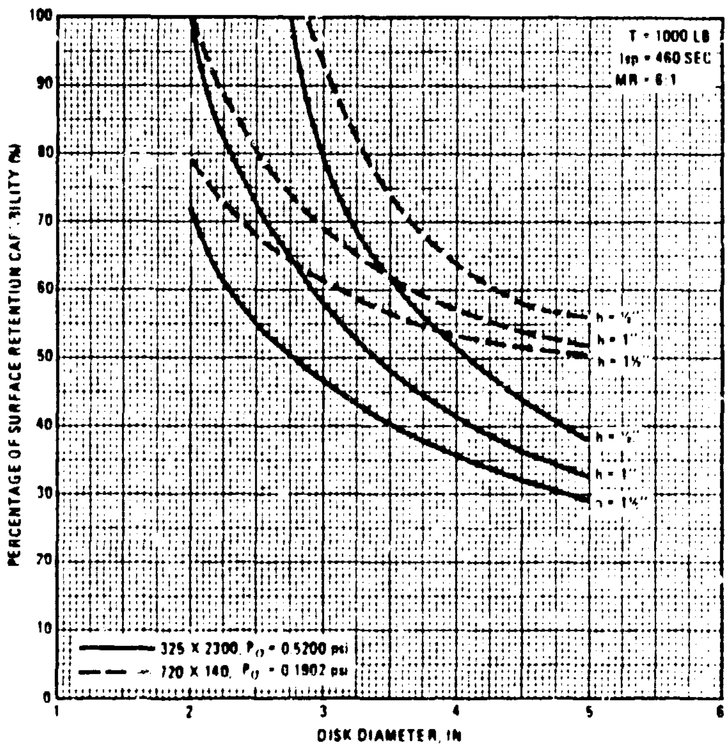


Figure 5-20. Total LO_2 acquisition device system pressure drop for flow into one branch channel, $\dot{m}$ = 1.863 lb/sec.

c. Thermal Conditioning. A primary objective of the LO_2 partial acquisition device is to provide adequate thermal protection to assure no vapor entry. In general, concern with any screen device is that conduction heat penetration or ullage heating may result in vapor formation within the screen volume. Of equal concern is the possibility that vapor generated in the feedline, as a result of engine heat soak-back and radiation heat transfer, will expand into the screen device. Fortunately, the toroidal tank configuration and pressurization system combine to provide an acceptable passive thermal conditioning system. The beneficial aspects of these systems is described below.

1. Heating Effects. Acquisition system heating will be from conduction heat transfer through the LO_2 feed duct and heat exchange with the ullage. Ullage heating will have a minimal effect upon the screen device because near-thermal-equilibrium conditions should exist throughout the mission. This is due to the MLI system and pressurization system. The approximate 15 MLI layers selected for the vehicle will reduce tank heating to the level where large temperature gradients will not be possible. Bubbling of helium through liquid during engine firing will tend to create equilibrium conditions. Thus, it is expected that the propellant contained within the screen device and the ullage will reside at about the same temperature.

   Heat conducted to the propellant through the LO_2 feed duct should be insignificant because of the duct length and tank wall properties. The feed duct from tank penetration to acquisition system is of sufficient length that most of the heat conducted along the duct will be convected to the tank propellants or ullage. Of greater importance is the fact that the major portion of heat conducted through the penetration will flow along the tank walls in preference to the feed duct. Tank wall thermal conductivity (aluminum) will be an order of magnitude greater than for the CRES feed duct. Furthermore, the tank cross-sectional area will be substantially greater for heat flow.

2. Feed Duct Vapor Generation. The feedline will contain pure liquid at the beginning of each zero-g coast period. Much of this liquid will be forced back to the propellant tank through the screen device as liquid boils during the extended zero-g coast period. Normally, it would be difficult to provide assurance that vapor would not be returned to the screen device. For this toroidal tank configuration, however, it appears that it will not reach the acquisition volume. It is estimated that as much as 18 inches of vapor may be contained within the tank volume, at equilibrium. Any vapor beyond this penetration length will condense. Condensation should occur because propellants will be subcooled (due to the tank helium partial pressure) relative to the vapor. Furthermore, heat conduction from the tank penetration along the tank wall will tend to cool the ullage and enhance condensation.

C-2

5.2.2.4 LH2 Tank Acquisition Device. The acquisition device for the LH_2 tank is shown in Figure 5-21. It is made up of six equally spaced screened branch channels manifolded into a solid walled raised duct connected to the outlet duct. The material is 304L CRES. The branch channels consist of fine mesh screen on the top and bottom of the channel with solid sidewalls. The screen is backed by perforated plate with 50% open area to withstand loads encountered during the relatively high acceleration (3 g) Shuttle ascent phase.

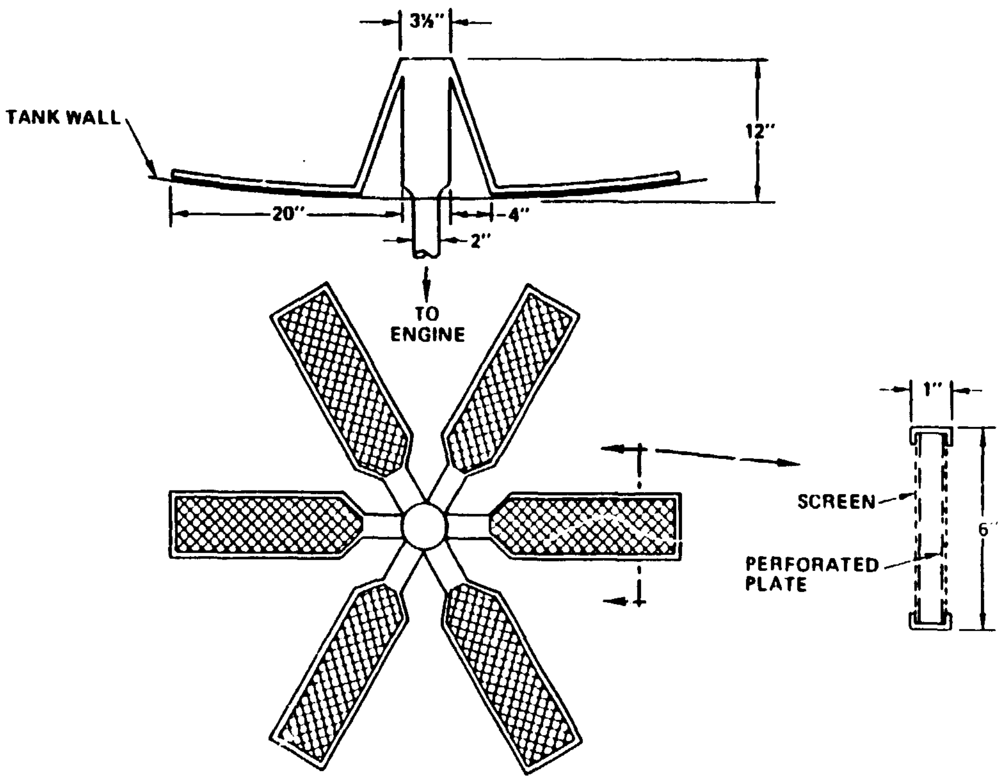


Figure 5-21. LH_2 tank acquisition device.

The number of branch channels chosen was based on the competing factors of decreasing the number of channels to minimize weight and increasing the number of channels to minimize residuals. The channel dimensions were chosen in order to maximize the ratio of screen surface area to channel flow area while keeping sufficient channel height to minimize channel flow pressure losses. The outlet duct was raised above the tank wall by 12 inches in order to prevent vapor from traveling up the propellant duct from the engine during a coast period and working its way into the screened channel. If vapor did migrate into the branch channels it might be ingested by the engine at an inopportune time. Intercepting it in the raised duct would allow the vapor to flow into the engine during the cooldown sequence when it would not be detrimental to engine operation. The raised duct diameter is larger than the propellant duct diameter in order to contain sufficient liquid in the raised duct for thermal conditioning during coast phases.

a. <u>LH_2 Acquisition Device Sizing.</u> As was the case for the LO_2 acquisition device, the LH_2 acquisition device was sized for a worst case 10° thrust misalignment and flow through only one branch channel. (See Figure 5-22.) The requirement to prevent vapor ingestion is again that the system flow losses not exceed the screen surface retention pressure at any point in the system. For the LH_2 acquisition device, this requirement is represented by:

$$\Delta P_{\sigma} > \Delta P_c + \Delta P_b + \Delta P_h + \Delta P_s + \Delta P_{cr} \tag{5-7}$$

where ΔP_{σ}, ΔP_b, ΔP_h, ΔP_s are as previously defined

$$\Delta P_c = \text{channel pressure loss} = \frac{f_s L_s + f_{us} L_{us}}{D_h} \frac{\rho V^2}{2 g_c} \tag{5-8}$$

where f_s = the friction factor for the screened channel section determined from Reference 14.

L_s = the length of the screened channel section.

f_{us} = the friction factor for the unscreened channel section, also from Reference 14.

L_{us} = the length of the unscreened channel section.

ΔP_{cr} = the pressure loss due to the reduction of flow area in the branch channel $= \dfrac{K_{cr} \rho_L V^2}{2 g_c}$ (5-9)

where K_{cr} = a pressure loss coefficient for flow area reduction taken from Reference 15.

All LH_2 properties used were for a vapor pressure of 14 psi. The LH_2 flow rate of 0.311 lb/sec assumes a 1000-lb thrust engine with an Isp of 460 seconds and a 6 to 1 mixture ratio of LO_2 to LH_2.

The combined pressure loss due to ΔP_c, ΔP_b, ΔP_h, and ΔP_{cr} was determined to be 3.925 psf. The major contribution to the pressure loss is due to ΔP_b, the pressure loss due to bending the flow. This pressure loss could be decreased by reducing the angle of the two bends, but doing so would increase the system size and weight in order to maintain the same screen area without any appreciable decrease in residuals.

Figure 5-23 gives surface retention pressure, ΔP_{σ}, versus screen bubble point diameter for screens in 14 psi LH_2. The lower surface tension of LH_2 compared to LO_2 results in lower retention pressures for the screens in LH_2 than are plotted in Figure 5-16 for the screens in LO_2. In order for the screen surface retention pressure to be greater than the system pressure loss, only the 325 × 2300 and 200 × 1400 screens were considered for use since the 3.925 psf loss already calculated exceeds all the other screen retention pressures.

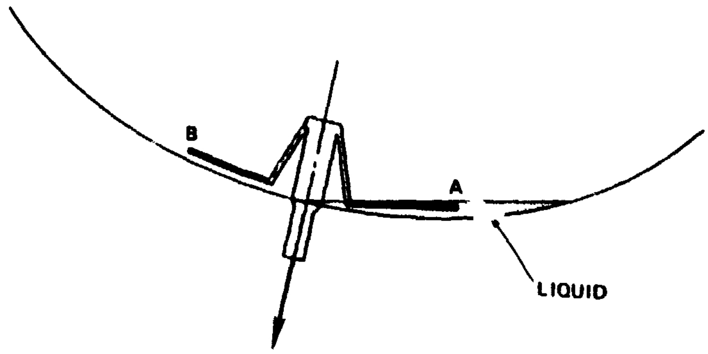


Figure 5-22. LH_2 acquisition with thrust misalignment.

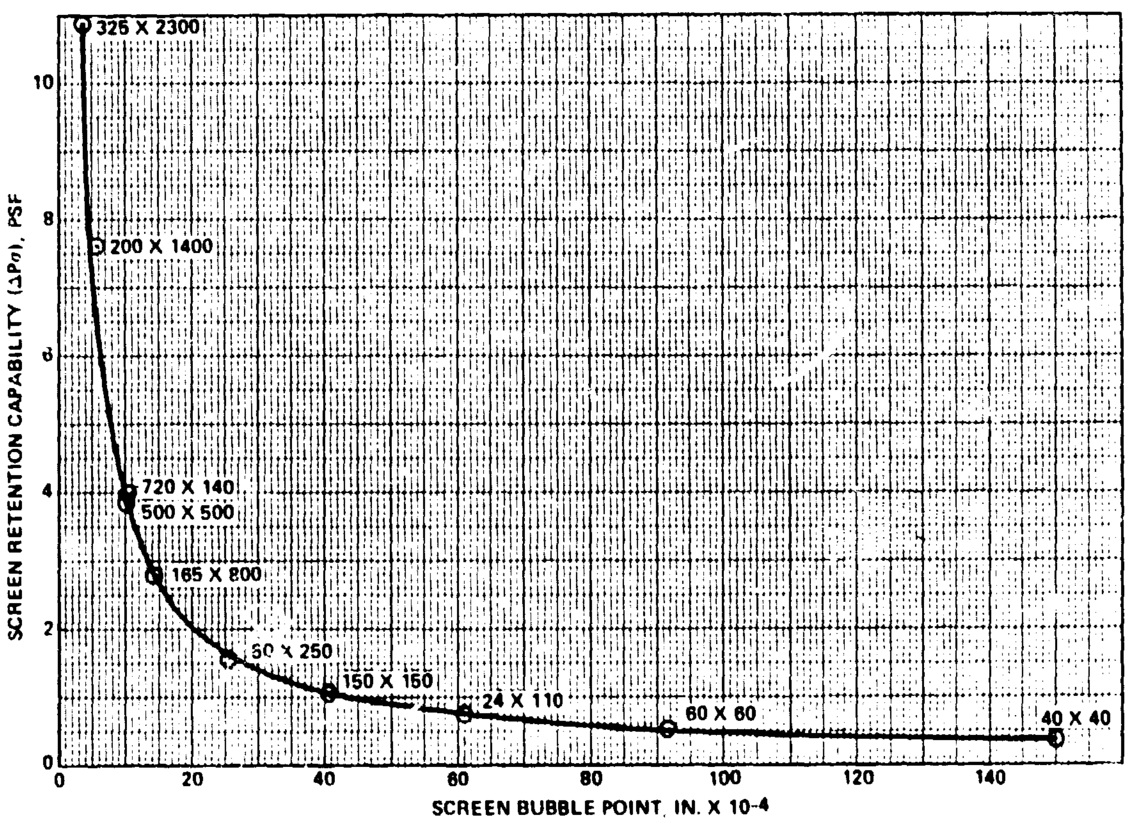


Figure 5-23. Screen surface retention pressure in 14 psi LH_2.

The total system pressure drop between points A and B in Figure 5-22, as a percentage of surface retention pressure, was evaluated for the two screen meshes for various screen flow areas. These data, presented in Figure 5-24, show that the 325 × 2300 screen outperforms the 200 × 1400 screen for all screen flow areas. Based on this, the 325 × 2300 screen was chosen for the LH_2 acquisition device. The surface retention pressure will be exceeded for the case of flow through one branch channel with the 325 × 2300 screen when less than 18 square inches of screen flow area is in contact with the liquid pool.

b. Thermal Conditioning. The LH_2 tank screen acquisition device will not benefit from the subcooled propellant environment available to the LO_2 device. The partial pressure of helium in the tank will not be adequate to expect vapor condensation. Although a thorough analysis was not conducted during the study, it is suspected that vapor penetration into the screen device may be prevented only if the LH_2 feed duct is cooled with an active heat exchanger. The heat exchanger would be in thermal contact with a one-foot length of feed duct downstream of the tank outlet. Liquid hydrogen would be expanded through a throttling device to a low pressure and temperature. The vent fluid would intercept penetration heat leaks as well as condense vapor.

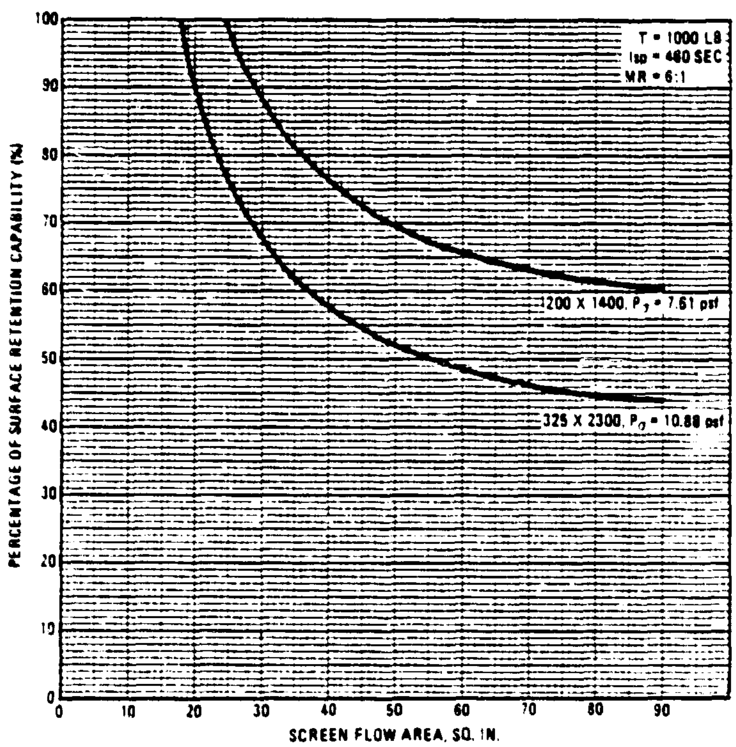
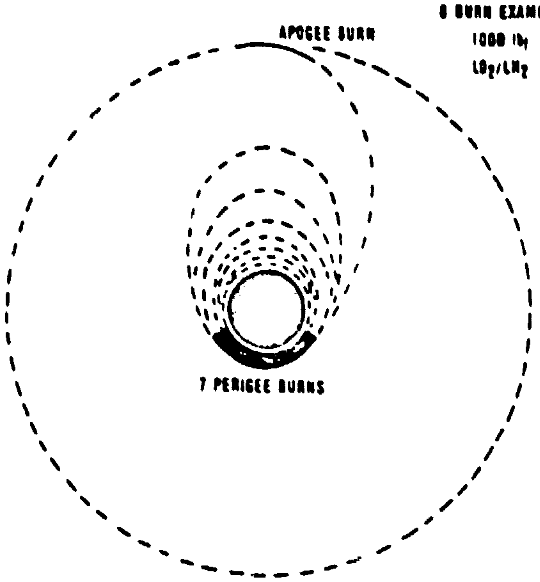


Figure 5-24. Total LH_2 acquisition device system pressure drop for flow into one branch channel, $\dot{m}$ = 0.311 lb/sec.

5.2.3 <u>INSULATION.</u> Analyses were conducted to determine tank insulation system requirements for the low thrust OTV. The baseline mission selected for this analysis is described in Figure 5-25. A 40-hour LTPS/LSS checkout and erection period was assumed to occur before first main engine firing. Additional requirements and inputs employed for this analysis are contained in Table 5-3 and Figures 5-26 through 5-28. These data were used for insulation system optimization.

Vehicle subsystem optimization will be based upon maximizing OTV payload capability. Consequently, it is necessary to include the interaction between subsystems. That is, an MLI system with very few radiation shields may be selected for minimum weight. But, the weight savings could be considerably less than the increased propellant boiloff. Thus, it may be necessary to compromise on a subsystem design point in order to optimize vehicle design.



8 BURN EXAMPLE
1000 lbf
LO_2/LH_2

- TRANSFER TIME — 23.5 HRS
- ACCELERATION RANGE — 017 → 047 T/W
- WEIGHT AT END OF APOGEE BURN — 21444 LBS

TRANSFER ORBIT PARAMETERS

BURN NO.	BURN TIME (HRS)	ALT AT INIT OF BURN (N MI)	COAST NO	COAST TIME (HRS)	COAST APOGEE ALT (N MI)
1	0.43	200	1	1.3	714
2	0.41	311	2	1.5	1354
3	0.40	443	3	1.8	2190
4	0.43	561	4	2.3	3425
5	0.46	664	5	3.0	5405
6	0.50	1006	6	4.7	9219
7	0.54	1319	7	4.4	19240
8	1.34	18978			

3316-41A

Figure 5-25. Mission profile selected for subsystems definition.

a. <u>RTLS Influence Upon OTV Design.</u> Return-to-launch-site (RTLS) requirements are imposed upon the OTV. These requirements will influence allowable vehicle tank pressure, which will influence MLI selection. Propellant tank pressures of 19 psia (LH_2 tank) and 25 psia (LO_2 tank) will be required to expel propellants during RTLS abort. Thus, the MLI system can be penalized only for propellant tank pressure increase in excess of the above stated values.

b. <u>MLI System Optimization.</u> The MLI system influence upon propellant tank design pressures, vapor residuals, and vent mass requirements has been assessed. This assessment was made for the main engine pressure requirements of Table 5-5, Item A, and for the pressurization system described by Item C.

Table 5-5. Assumptions and requirements for insulation optimization study.

A. Main Engine Requirements

Propellant	NPSP, PSID	Selected Tank ΔP, PSID	Minimum Inlet Pressure, PSIA
LO_2	1.0	1.3	16
LH_2	0.5	0.8	16

B. Mission Payload Partials

Item	$\delta PL/\delta W$, lbm/lbm
Hardware weight (tanks, insulation, etc.)	-1.0
Vent mass (T-0 to first main engine start)	-0.6
Vapor Residuals @ final MECO	-1.6

C. Selected Pressurization Systems

LH_2 Tank

1. Engine start pressures provided by direct helium injection into ullage.
2. Main engine burn pressures maintained by autogenous pressurization.

LO_2 Tank - Engine start and main engine burn pressures provided by direct helium injection into liquid.

D. OTV Configuration

Propellant Tank	Surface Area, ft^2	Volume, ft^3	Design* Pressure, PSIA
LH_2	599	1360	19
LO_2	425.8	505.8	25

*Determined from RTLS Abort Dump Calculations.

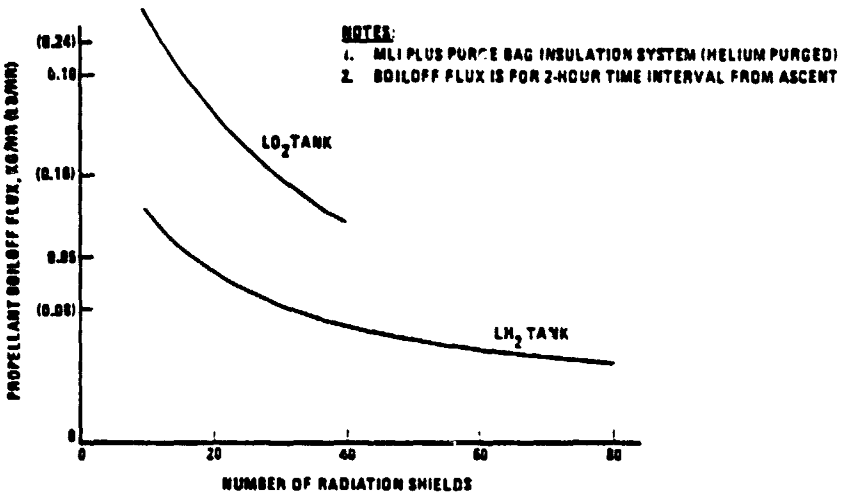


Figure 5-26. OTV tanks average boiloff flux during ascent.

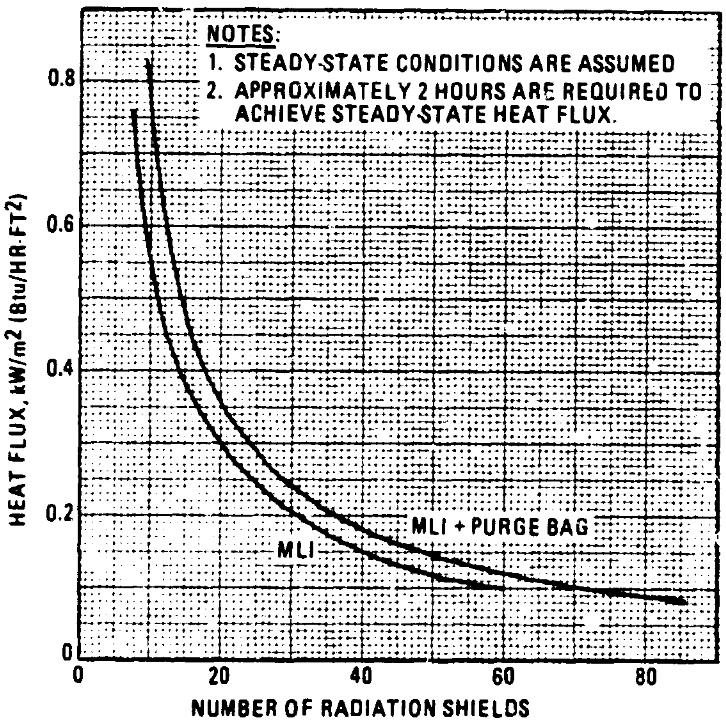


Figure 5-27. Space boiloff rates for insulated LH_2 and LO_2 tanks.

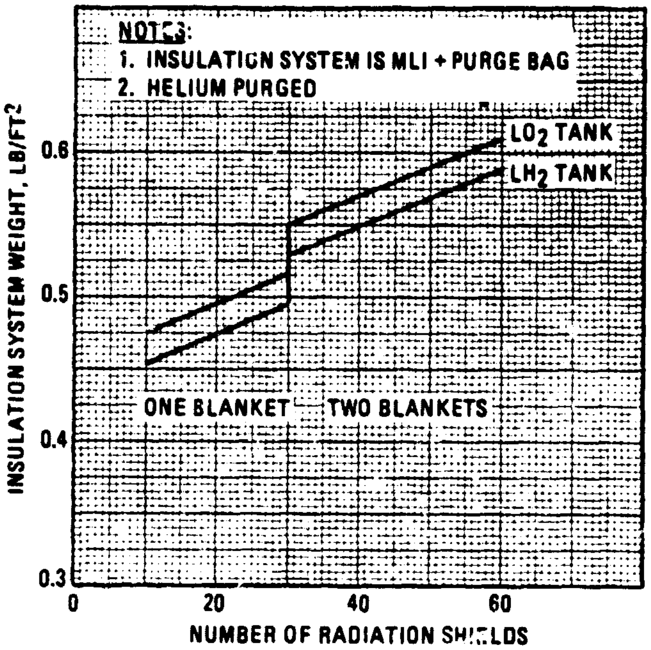
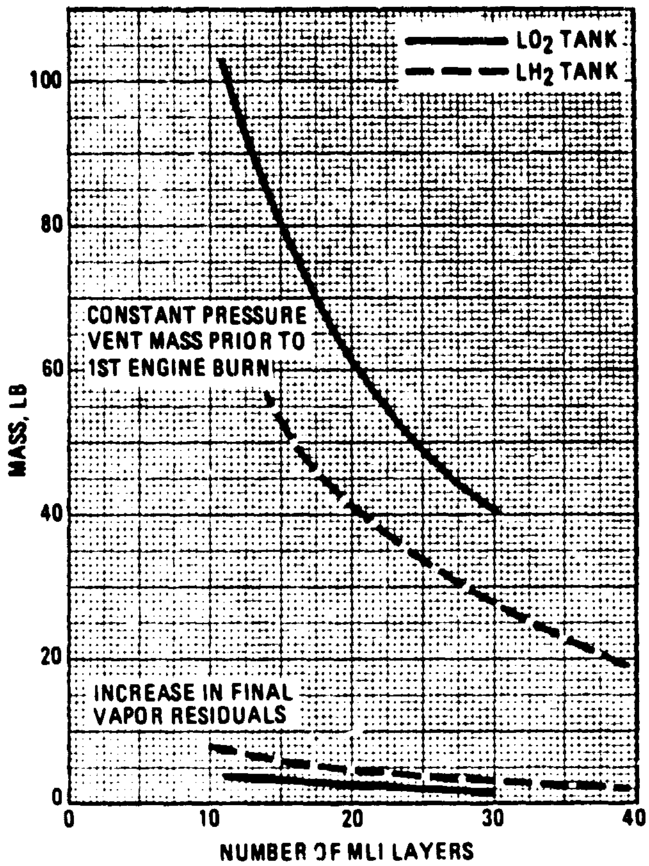


Figure 5-28. MLI insulation system weight.

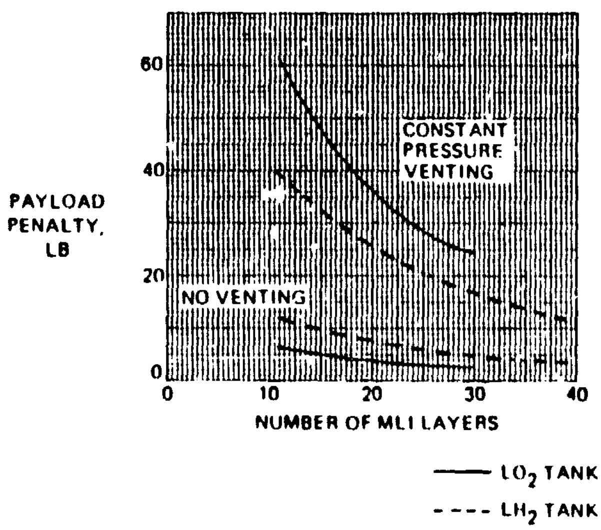
c. LTPS/LSS Checkout. The first trade performed was to determine whether the propellant tanks should be vented during the 40-hour checkout and erection period. The alternative to venting is to lock up the propellant tanks and absorb heat input, which increases tank pressures during this period and increases final vapor residuals. Heat input to the propellant tanks was determined from Figures 5-26 and 5-27 and tank surface area given in Table 5-3, Item D. The resultant vent mass is given in Figure 5-29 as a function of MLI layers. If, however, a no-vent option is used, an increased vapor residual mass will be experienced.

Payload penalties are given in Figure 5-30 for the vent and no-vent options. The no-vent option is always preferred to the vent option. This result is due in part to the fact that tank pressure increase during the 40-hour checkout will not exceed the tank pressures required for RTLS abort. Consequently, a tank weight increase is not needed to accommodate the increased tank pressure. The no-vent option does not apply during Shuttle powered phase because rapid pressure increases resulting from high heating rates occurring during this period preclude not venting. Thus, the no-vent option is applicable from SSME cutoff until OTV first engine burn.



NOTES:
1. VAPOR RESIDUAL INCREASE OCCURS ONLY IF PROPELLANT TANK VENTING IS NOT PERMITTED.
2. NO LH_2 TANK WEIGHT INCREASE REQUIRED SINCE PRESSURE WILL NOT RISE ABOVE ALLOWANCE VALUE OF 19 PSIA.
3. NO LO_2 TANK WEIGHT INCREASE REQUIRED SINCE PRESSURE WILL NOT RISE ABOVE ALLOWABLE VALUE OF 25 PSIA.
4. VAPOR RESIDUAL INCREASE CAUSED BY TANK VAPOR PRESSURE INCREASE PRIOR TO MES 1.
5. VENT MASS BASED UPON HEAT INPUT FROM SSME CUTOFF TO CUTOFF + 42 HOURS.

Figure 5-29. Vent option vs. no-vent option during LTPS/LSS checkout period.



NO-VENT CONDITION PRESSURES DO NOT EXCEED DESIGN VALUES (SET BY ABORT DUMP REQUIREMENTS)

19 PSIA – LH_2
25 PSIA – LO_2

ZERO "G" VENT/MIXER

PAYLOAD PENALTY FOR 40 HR CHECKOUT AT LEO IS MINIMIZED WITH NO-VENT OPTION

Figure 5-30. 40-hr checkout (payload penalty).

5.2.3.1 Torus Tank Insulation. Figure 5-31 shows how MLI system weight and vapor residual mass will be influenced by number of MLI layers. Also included is the increased vapor residual mass caused by the propellant tank vapor pressure rise during the no-vent heating period from T-0 to MES1. Payload penalty is given in Figure 5-32 as a function of MLI layers, and is minimum for about 15 layers of MLI. It should be emphasized, however, that variations in payload penalty are sufficiently small that any MLI system selection between 10 and 30 layers should be acceptable.

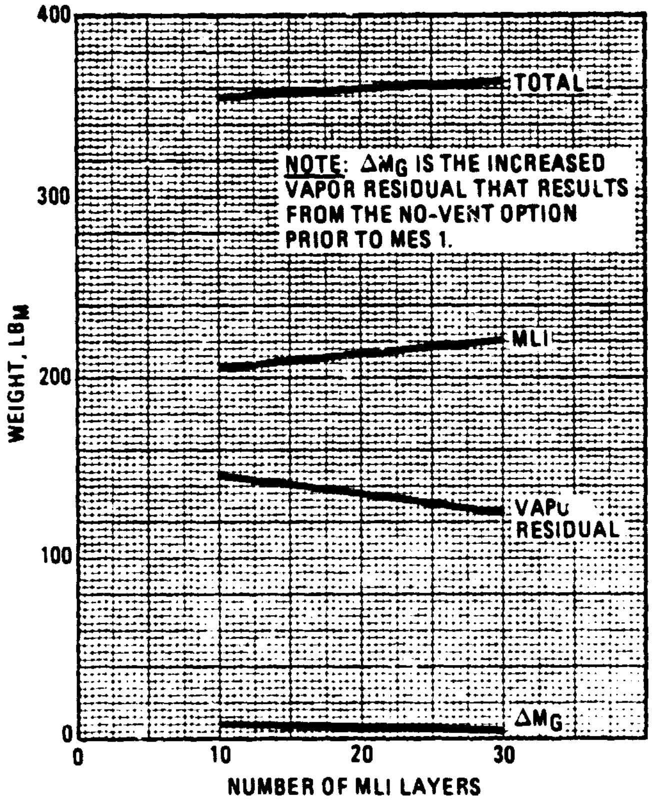


Figure 5-31. MLI influence upon LO_2 tank vapor residuals.

Design details of the insulation and purge system are presented in Figures 5-33 through 5-35 (Layout 60) for the LO_2 (torus) tank showing general arrangements, construction details, and techniques for penetrations such as support struts and access holes.

The insulation is basically a lay-up of multi-layer radiation shields separated by dacron flocking spaced on 3/8 inch centers in a triangular pattern. This system (called "Superfloc") was developed and tested by GDC on an 87-inch Ellipsoidal 2219 aluminum alloy tank. The first "Superfloc" system developed under 1968 IRAD funds used double aluminized mylar shields with "Lexan" fasteners. A second system tested used double goldized "Kapton" with P.P.O. (polyphenylene oxide) fasteners and an external purge enclosure. This second effort was accomplished under Contract NAS8-27419 for MSFC in 1975. A third system was recently constructed using coated double aluminized "Kapton" under Contract NAS8-31778 for MSFC. This third system, together with an acquisition device, is scheduled to be tested at MSFC.

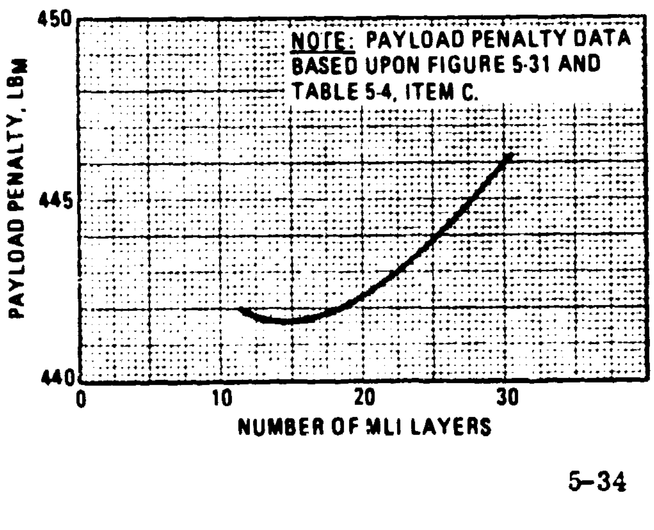


Figure 5-32. Payload optimization of LO_2 tank MLI system.

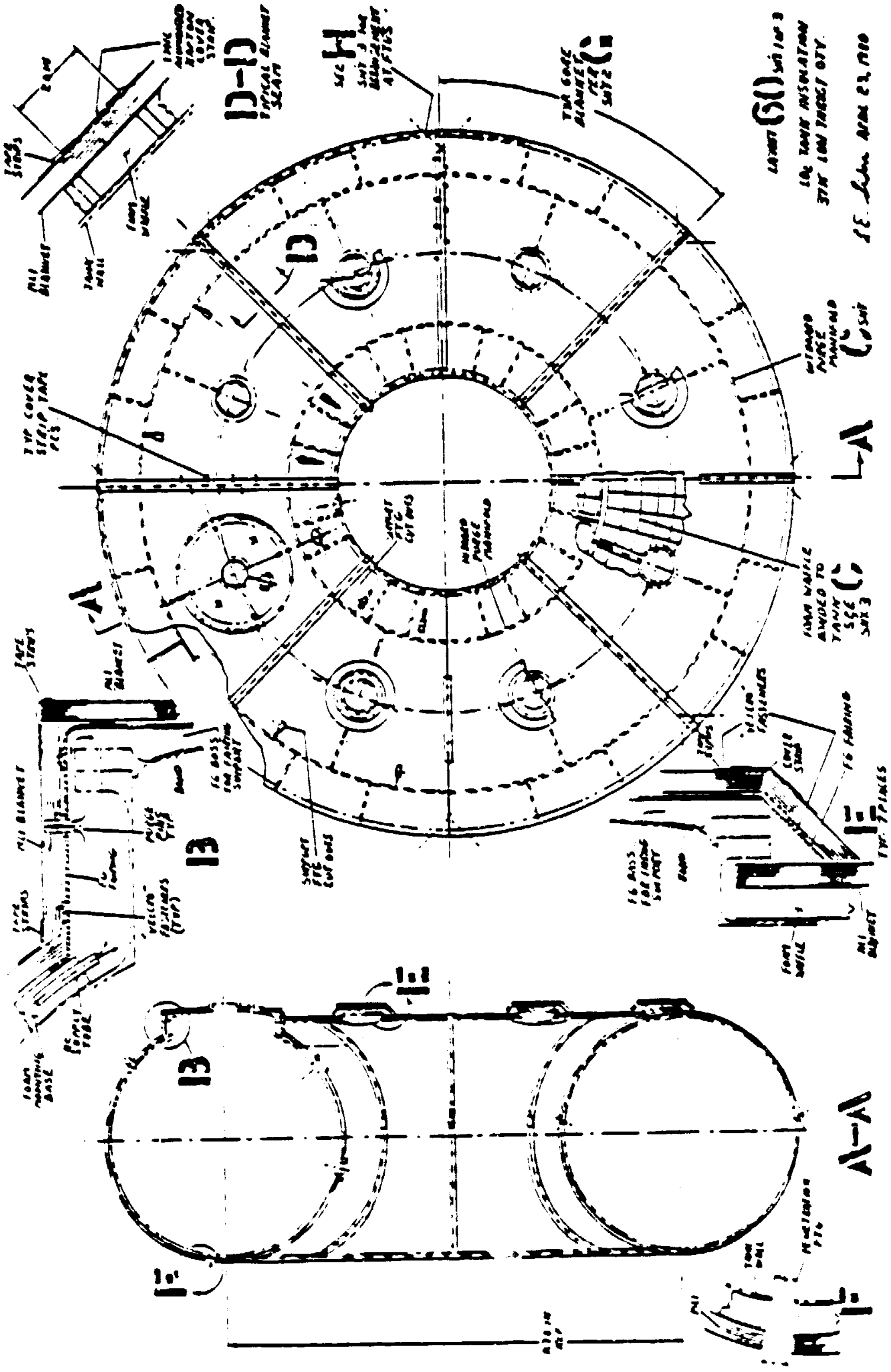


Figure 5-33. Torus insulation design.

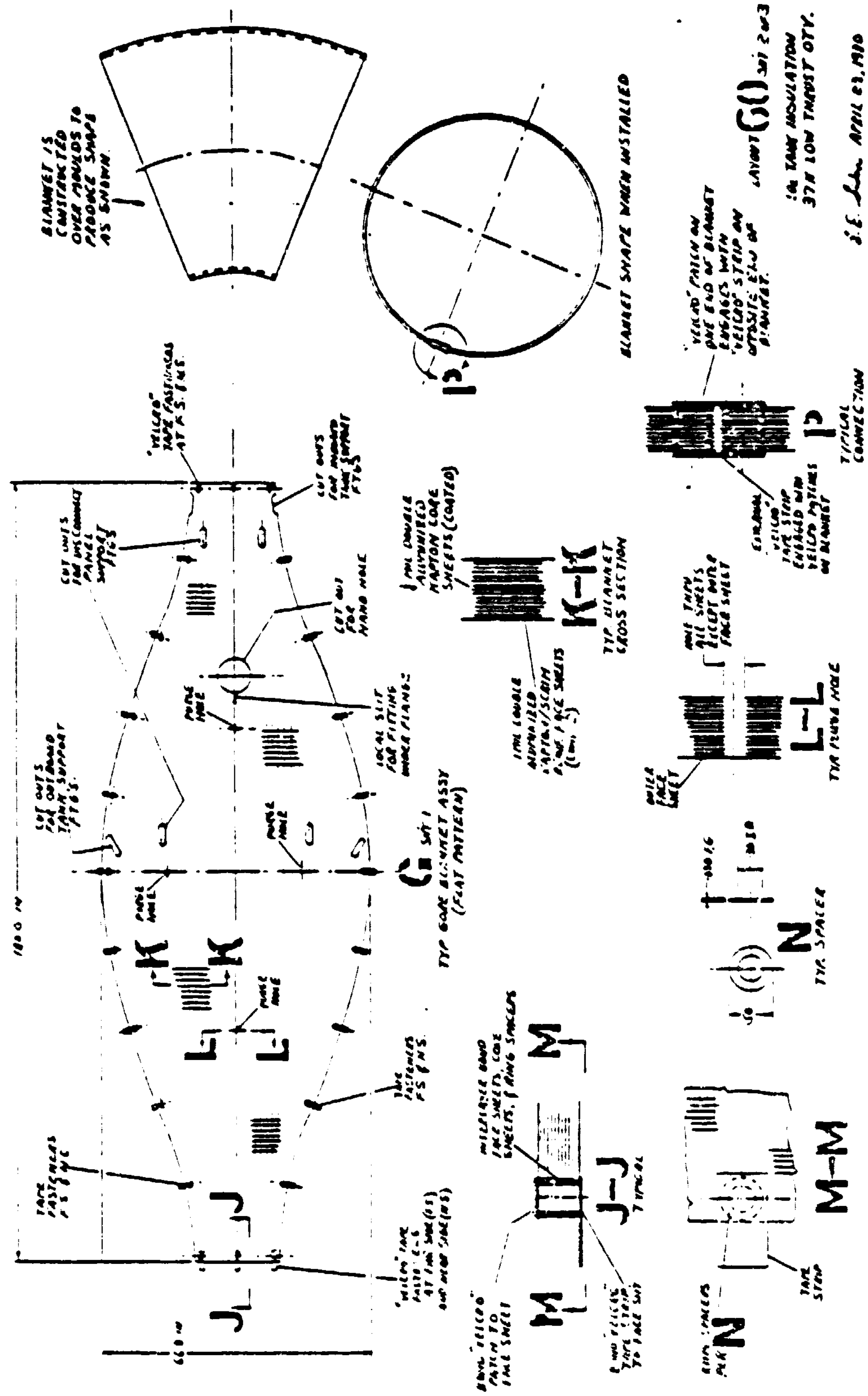


Figure 5-34. Torus insulation blanket (8).

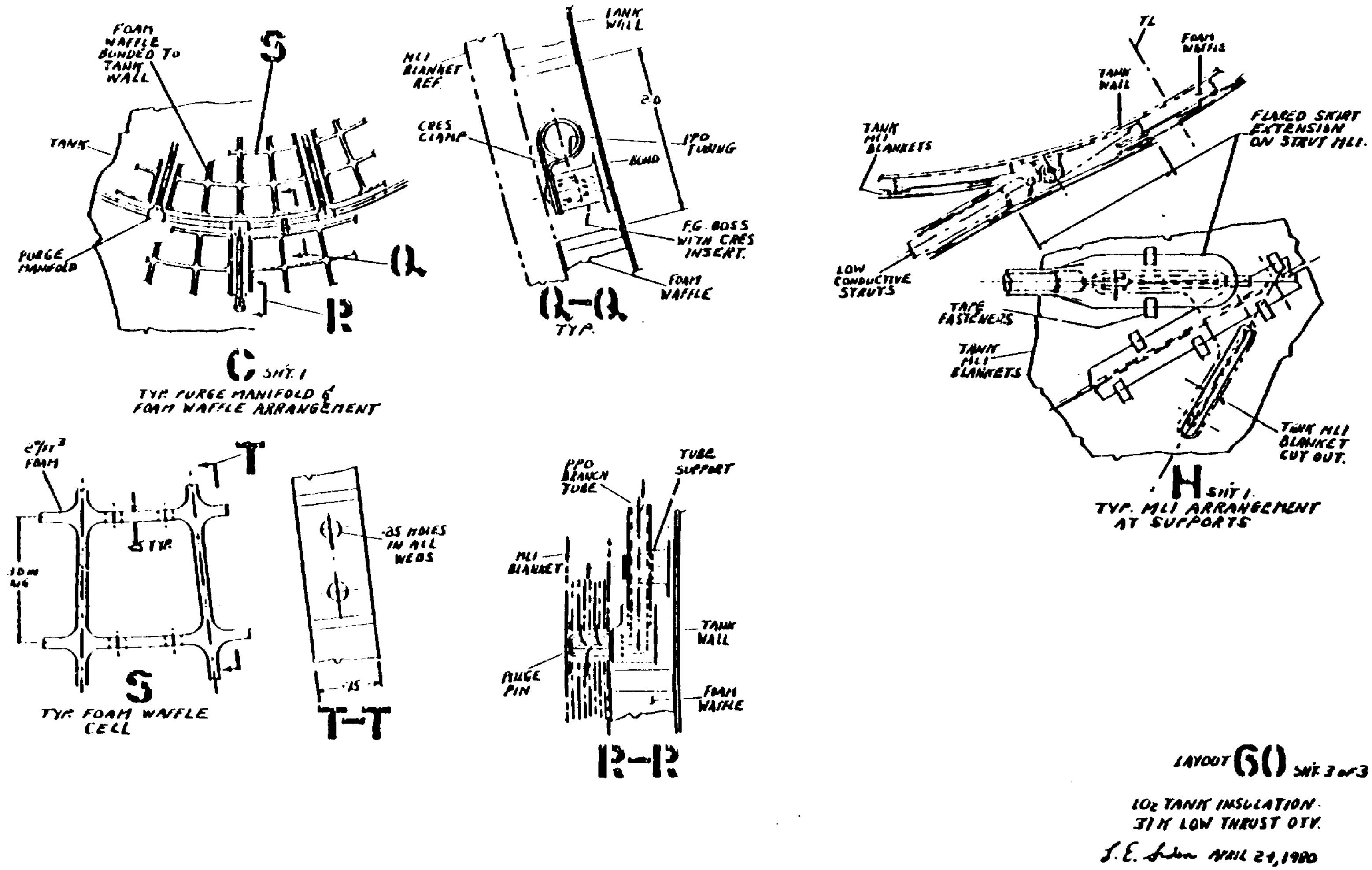


Figure 5-35. Torus insulation purge.

The design shown features a tank-mounted purge gas distribution system. The complete tank, including the purge system, is enveloped with the multi-layer insulation (MLI). Although the configuration is different than those previously constructed, the same basic techniques are used in this application. The purge gas enclosure is not required for the oxidizer tank.

a. Purge System. Gaseous nitrogen is injected into the MLI lay-up at approximately 36 points. (See Figure 5-36.) To accomplish this, two ring-type supply manifolds equipped with branch tubes are mounted on the tank. Each branch tube is equipped with a purge pin which engages with a hole in the MLI. Both the manifolds and the branch tubes are attached using fiberglass (F.G.) bosses equipped with self-locking CRES inserts. The bosses are bonded to the tank wall and the tubes are attached with CRES clamps and screws. Upon pressurizing the manifolds, the nitrogen gas flows through the purge pins, through the MLI layers, and exhausts at the edges of the MLI blankets.

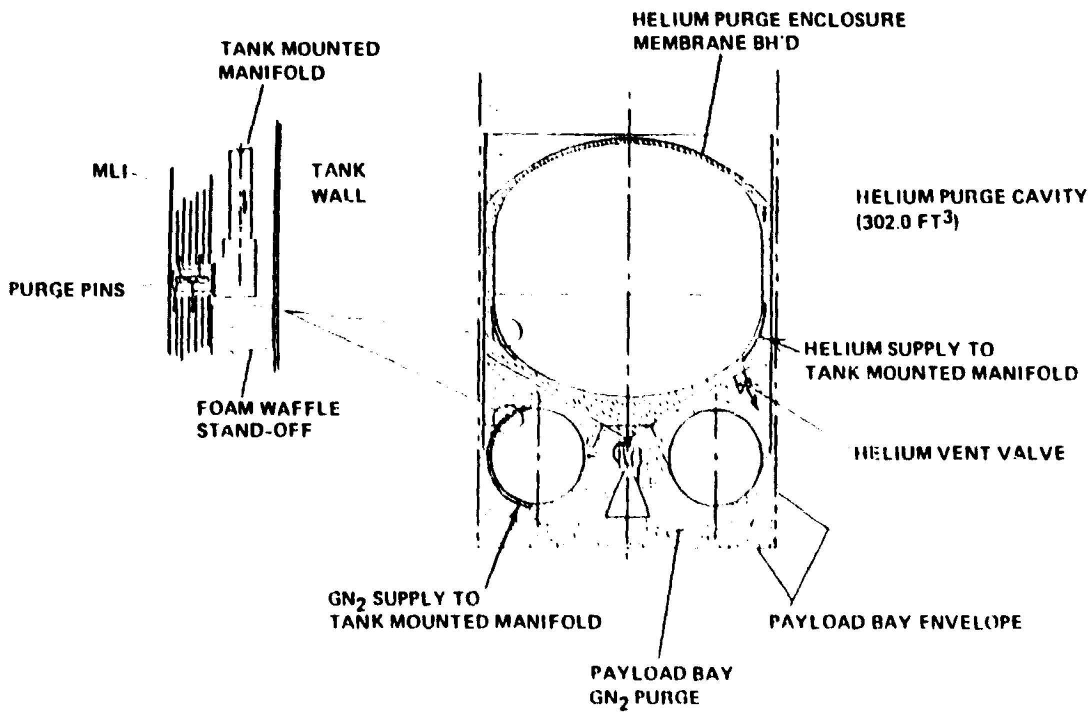


Figure 5-36. Purge system enclosure.

The purge manifolds, support bosses, clamps, and fittings protrude approximately 3/4 inch above the surface of the tank. MLI installed over an irregular surface of this type would cause local compression between layers and would prevent a uniform fit. To avoid these surface discontinuities, foam blocks cast in a waffle pattern are located between the purge tubing and bonded to the tank. The foam blocks are not part of the insulation system and serve

only as a uniform base for mounting the MLI. The oxidizer tank purge system, which uses gaseous nitrogen without a purge enclosure, reduces vehicle weight, saves design and construction costs, and reduces ground-hold operation expenses.

b. MLI System. The MLI is applied to the tank in eight 45° preformed blankets. A flat pattern layout of a typical blanket is shown in Figure 5-34. The cross section is a series of 1/4 MLI core sheets sandwiched between two scrim-reinforced face sheets. Both face sheets and the core sheets are coated double aluminized "Kapton". The coating is an organic film which preserves the thermo characteristics of the aluminized surfaces. GDC developed coated aluminized "Kapton" under Contract NAS8-31778 for MSFC in 1978.

The purpose for the scrim-reinforced face sheets is to provide load carrying membranes and to improve general handling without damage to the 1/4 MIL core sheets. To prevent core sheet shifting relative to the face sheets, the blanket is interlayer spot bonded at 24 places. These spot bonds also serve as hard points for attaching fasteners. The typical cross section uses fiberglass washers between each layer for maintaining a uniform spacing. The fiberglass washers are coated on both sides with adhesive, stacked between the MLI layers, and bonded into a single hardpoint. "Velcro" hook sections on one end are engaged with the pile sections on the opposite end. The fasteners are engaged simply by applying thumb pressure at the hard points.

Several cutouts in the blankets are required for tank support struts, plumbing penetrations, disconnect panel support fittings, and access holes. To prevent tearouts, the core sheets are locally reinforced with 1 MIL aluminized Kapton tap strips at the perimeter of each hole. Each blanket is purged at four points with holes cut in the core sheets and through one face sheet.

c. Penetrations. The access opening, the hand holes, and the support fittings are significant penetrations which must be insulated with the same system used on the tank walls. The entire opening is enveloped with a fiberglass "can-shaped" fairing which is attached to the door with fiberglass bosses which, in turn, are bonded to the access door. The fairing, which forms a plenum chamber around the access opening, is insulated with one wrap-around girth blanket and one circular cap blanket. The blankets are constructed similar to the large core sections and are attached to the fairing with "Velcro" fasteners. Purge pins bonded to the fairing engage with the blankets at three points. Overlap butt joints are used between blankets and held in position with 3/4-inch wide aluminized Kapton tape strips spaced on approximately 3-inch centers. A branch from the helium supply manifold injects helium gas into the plenum chamber, through the purge pins, through the MLI layers, and exhausts at the blanket edges between the tape strips. Should access to the tank be required, the edge tape strips are cut, the cap blanket removed and the fairing (with girth blanket) detached from the access door.

A similar arrangement is used for the hand holes, except the fairing is a shallow-pan-type configuration. The tank wall insulation terminates under the opening flange, and the fairing blankets intersect with mitered joints equipped with cover strips. Since the blanket sections are small, no purge pins are used. Purging is accomplished by diffusion from the helium atmosphere inside the purge enclosure.

The tank is attached to the vehicle structure with low conductive struts which are enveloped with MLI. A flared or half-boot area at one end of the strut insulation overlaps the tank fittings and is held in position with aluminized Kapton tape strips. The cavity around the fittings and the strut MLI is purged by helium gas flow from the blankets and by diffusion. The blanket stops at the penetration with a simple circular cutout. The insulation on the duct or tube forms an overlap butt joint with the tank blanket.

5.2.3.2 LH2 Tank Insulation. Figure 5-37 shows how MLI system weight and vapor residual mass will be influenced by the number of MLI layers. Also included in the figure is the increased vapor residual mass caused by propellant tank vapor pressure rise during the no-vent heating period from SSME cutoff to MES 1. Payload penalty is given in Figure 5-38 as a function of MLI layers. This system is optimized at about 17 layers. However, 30 layers of MLI was selected to satisfy prelaunch insulation system requirements.

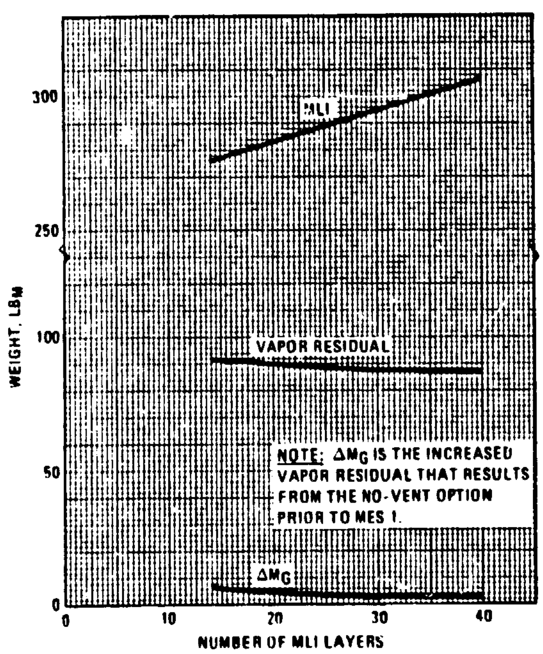


Figure 5-37. MLI influence upon LH_2 tank vapor residuals.

The basic insulation and purge system arrangement is schematically shown in Figure 5-36. MLI materials, construction, lay-up, and attachment techniques are similar to those for the torus tank. The hydrogen tank requires a helium purge distribution system with a purge gas enclosure. The purge gas enclosure consists of a lightweight membrane (scrim reinforced Kapton). The

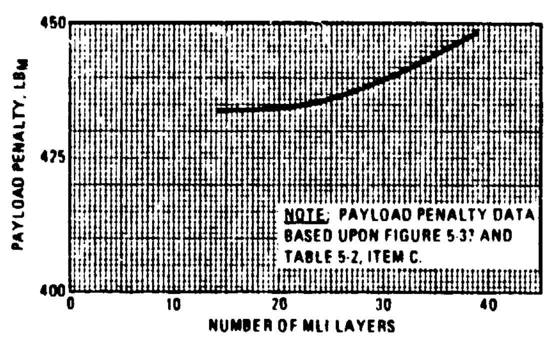


Figure 5-38. Payload Optimization of LH_2 tank MLI system.

structural shell of the vehicle is a part of the enclosure in order to save weight. The purge gas volume is 302 ft^3. Helium is supplied to the purge pins through a tank-mounted manifold. During ascent, the purge system MLI is required to vent to an ambient pressure environment. To maximize thermal performance, the MLI interstitial pressure must vent down to 10^{-4} torr within one hour after launch. An analysis is required to determine a venting approach that satisfies the above requirements.

5.2.4 PRESSURIZATION, TANK PRESSURE CONTROL, AND ABORT DUMP. The purpose of these systems is to satisfy main engine NPSP requirements for transient start and steady-state operation, and to maintain propellant tank pressure control throughout the mission. The pressurization system includes pressurant storage, lines, and valves needed for pressurant transfer to the propellant tanks, and software to monitor and command pressurization. The tank pressure control system includes hardware and software needed to maintain propellant tank pressures within prescribed limits during the mission, especially during coast periods between engine firings. It is expected that the same software system will monitor and command both pressurization and tank pressure control systems.

5.2.4.1 Pressurization System. The pressurization system selected for this vehicle will provide helium to each propellant tank to satisfy main engine NPSP requirements, autogenous pressurant for the LH_2 tank during engine firing, and helium pressurant for the LO_2 tank during engine firing. A pressurization system schematic is shown in Figure 5-39. Helium pressurization for main engine start was selected to simplify requirements for the main engine system design, i.e., eliminating the need for engine boot-strap capability.

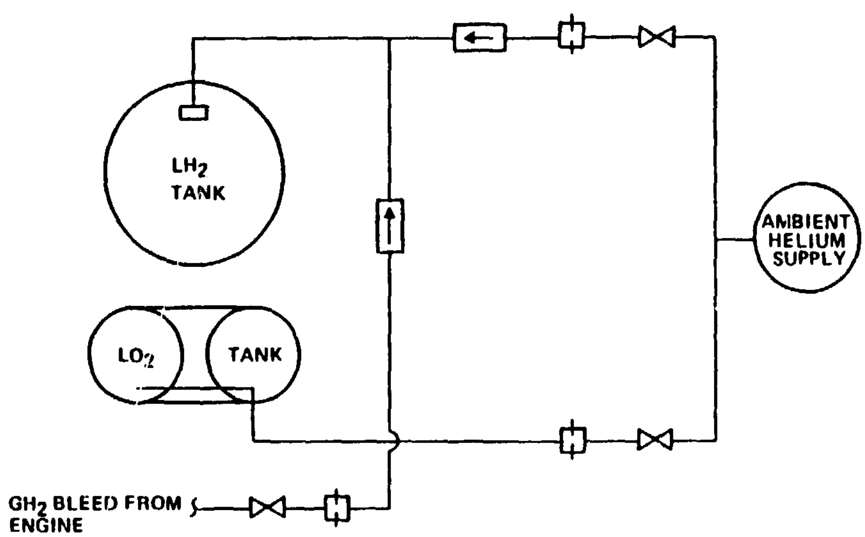


Figure 5-39. Propellant tank pressurization system.

a. Main Engine Requirements. The pressurization system will be designed to provide main engine NPSP throughout the low thrust OTV mission. This means that both engine NPSP and absolute pressure requirements must be satisfied. Tank pressurization ΔP can be determined from the following equation:

$$\Delta P = \Delta P_{NPSP} + \Delta P_L + \Delta P_{ACC} + \Delta P_S$$

where ΔP = required tank pressure

ΔP_{NPSP} = engine NPSP

ΔP_F = feedline frictional losses from the tank outlet to engine inlet

ΔP_{ACC} = propellant acceleration losses during engine start transient (ΔP_{ACC} = 0 for steady state engine firing)

ΔP_S = pressurization system ΔP consisting of pressure sensing accuracy, deadband ΔP, etc.

ΔP_X

ΔP_{NPSP} values of 0.5 psi (LH_2 side) and 1.0 psi (LO_2 side) were selected for pressurization system sizing. The low propellant flowrates should result in low values for ΔP_F and ΔP_{ACC}. Consequently, it was decided to combine these terms with ΔP_S and use a representative value of 0.3 psid. Thus, required tank ΔP_S of 0.8 psi (LH_2 tank) and 1.3 psi (LO_2 tank) were selected for this study. (See Table 5-5.)

b. Software Controls. In addition to NPSP, main engines may also have a minimum operating pressure level. For this study, a minimum operating pressure of 16 psia was selected. Software must be available to satisfy both requirements. Software logic will be relatively simple: pressurization valves will be commanded open to satisfy the absolute pressure requirement. At other times it may be necessary to reduce propellant tank pressures prior to pressurizing with helium, to avoid exceeding tank pressure allowables. The software control system will be capable of discriminating between pressurization and tank pressure control requirements.

c. LH_2 Tank Pressurization. The hydrogen tank will be pressurized with helium from the ambient storage bottle prior to main engine start. Helium will be introduced into the tank through a diffuser to avoid the possibility of liquid spray created by a gas jet. Tank ΔP will be maintained with helium until after main engine start, when autogenous pressurant is available from the main engine. Helium mass usages for the eight-burn mission were determined using empirical relations developed from Centaur vehicle flight experience. These mass quantities are summarized in Table 5-6.

Table 5-6. Helium pressurant mass quantities for low thrust OTV mission.

Press'n Period	Engine Start Helium, lb		Steady-State Helium, lb
	LH_2 Tank	LO_2 Tank	LO_2 Tank
1	0.26	0.04	0.20
2	0.19	0.05	0.19
3	0.26	0.07	0.05
4	0.33	0.09	0.04
5	0.41	0.12	0.03
6	0.49	0.15	0.00
7	0.56	0.18	0.00
8	0.70	0.21	1.42
Total	3.2	0.91	1.91

Autogenous pressurant flow will commence shortly after steady-state engine conditions are established. A pressurant temperature of 350°R was selected for this study. As with helium, hydrogen will be introduced through the pressurization diffuser to minimize interaction with the propellant. During engine firing, heat exchange will occur between the ullage and tank walls, and between the ullage and liquid surface. As a result, both the tank walls and liquid surface will increase in temperature during engine firing. Warm tank wall temperatures present the potential for a sudden pressure rise after MECO because propellant will evaporate upon contact. Also, a stratified liquid surface could adversely affect main engine NPSP requirements during the final OTV engine firing. Fortunately, analysis has shown that these conditions are substantially less serious for an eight-burn mission that for a one- or two-burn mission. It was concluded that autogenous pressurization was suitable for the low thrust vehicle.

d. <u>LO_2 Tank Pressurization.</u> Helium pressurization of the LO_2 tank will be different from that of the LH_2 tank; helium will be injected beneath the liquid surface rather than into the ullage. The advantage of this technique (which has been proven on the Centaur vehicle) is that less helium is required than for direct ullage injection. Reduced helium usage is due to the considerable oxygen evaporation into the helium bubbles that occurs during pressurization. In fact, the evaporated oxygen is responsible for a major portion of tank ΔP.

Because of the small quantity of helium required, the liquid injection technique was also used during each engine burn. This method has the advantage of maintaining near-thermal equilibrium conditions during engine firing, so that pressure shifts following each MECO will be minimal. Another advantage for this tank pressurization method is that helium introduced throughout the mission will have an accumulative effect so that pressurant mass requirements can be reduced for subsequent pressurizations. For this study, the accumulative effects of helium for engine start pressurization were not considered so that conservatively high helium usages could be calculated. However, the engine start helium was accounted for in calculating engine burn helium requirements. These quantities are given in Table 5-4. Note that a substantial quantity of helium is required during the final engine burn. This results from the need to maintain a minimum engine inlet pressure of 16 psia.

5.2.4.2 Tank Pressure Control. Propellant tank pressure control during each of the zero-g coast periods will be maintained with a thermodynamic vent system (TVS). The primary components of the TVS are a heat exchanger and a mixing device (Figure 5-40). The vent side, or cold side, of the heat exchanger will accept any combination of liquid and vapor, expand it to a reduced pressure and temperature, which allows for heat exchange with the tank side, or hot side, fluid. The heat exchanger is sized to guarantee that vapor is always vented, even with pure liquid at the cold side inlet.

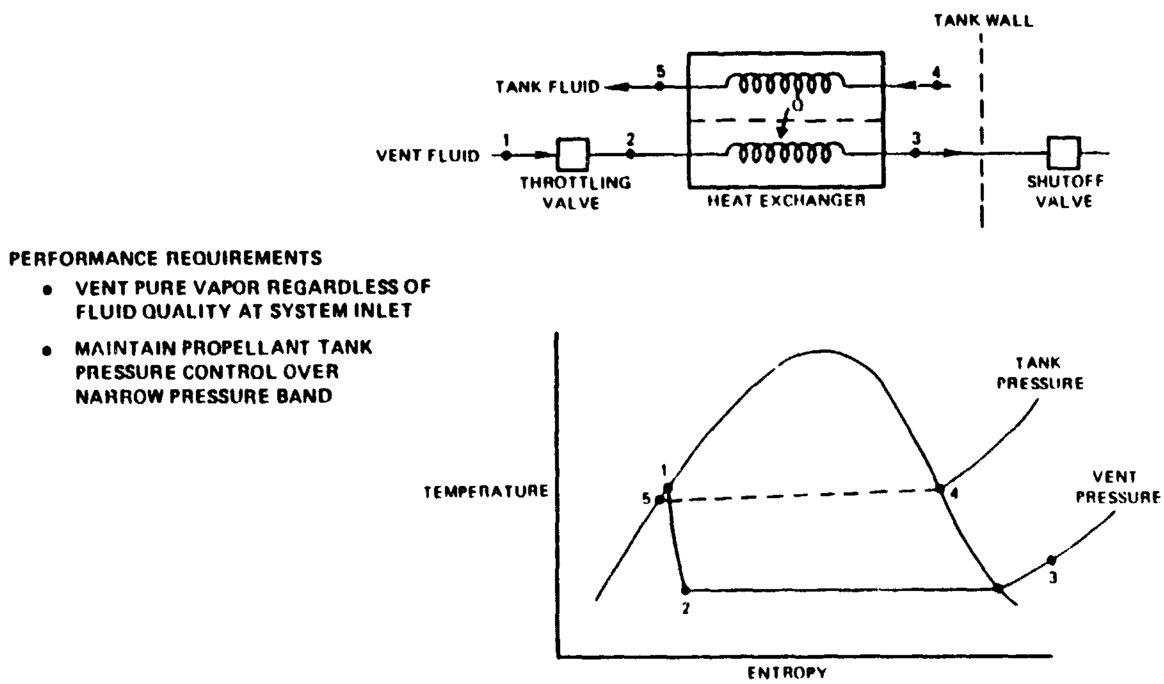


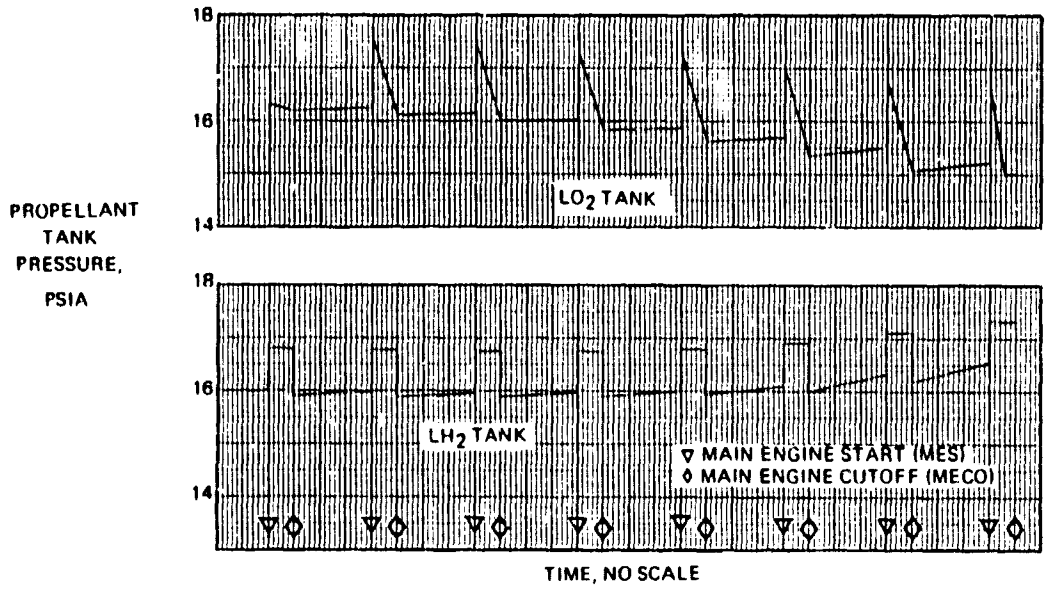
Figure 5-40. Zero-g thermodynamic vent system.

The mixing unit has a two-fold function: to pump the tank side fluid over the heat exchanger surfaces, and to mix the fluid with the propellant bulk. Forced convection flow over the heat exchanger will provide the heat transfer mechanism needed to completely vaporize the vent fluid. However, propellant tank pressure decay will not necessarily occur until the hot side vent fluid is mixed with and cools the bulk propellants. Because the TVS can satisfactorily operate with either liquid or vapor at the vent inlet, propellant tank pressure control can be maintained in a zero-g environment.

There may be instances where venting may be required in order to maintain propellant tank pressures within acceptable limits. This was not the case for the baseline eight-burn mission.

Mission propellant tank pressure profiles are given in Figure 5-41. The technique of bubbling helium through LO_2 causes vapor pressure decay during engine firing. Heat input during the coast periods will increase vapor pressure, but not enough to compensate for the decay during pressurization. Consequently, tank pressure will gradually decay throughout the mission as liquid vapor pressure decays.

Liquid hydrogen tank pressure during the multi-burn OTV mission will be influenced by the autogenous pressurant and propellant tank heating. At each MECO, the possibility of a pressure spike and pressure decay exists. As previously discussed, the pressure spike can occur when liquid quenches the warm tank walls. A pressure decay would occur once propellant mixing with the ullage established thermal equilibrium. These pressure spikes and decays are shown at each MECO condition.



- LO_2 TANK PRESSURIZED WITH HELIUM FOR ENGINE START AND ENGINE BURN
- LH_2 TANK PRESSURIZED WITH HELIUM FOR ENGINE START; AUTOGENOUS PRESSURIZATION FOR ENGINE BURN
- ENGINE NPSP REQUIREMENT
  - 1.0 PSI LO_2
  - 0.5 PSI LH_2

Figure 5-41. Propellant tank pressure histories for eight-burn OTV mission.

5.2.4.3 Abort Dump. The return-to-launch-site (RTLS) requirements imposed upon the OTV are given in Table 5-7. These requirements may influence vehicle tank pressure allowables and pressurization system selection. The most demanding condition is for dumping propellants within 300 seconds. By using applicable data available from the Centaur-in-Shuttle Integration Study (Reference 16), helium pressurant requirements and propellant tank pressures during RTLS were determined for OTV. These data are summarized in the table and are based upon 5-inch I. D. propellant dump lines designed for Centaur. Note that propellant tank pressures of 19 psia (LH_2 tank) and 25 psia (LO_2 tank) will be required to expel propellants during RTLS abort.

Table 5-7. OTV abort dump pressurization system requirements.

OTV Abort Dump Requirements

1. Dump cryogens in ~ 300 seconds.
2. Repressurize propellant tanks following dump.
3. Maintain MLI and engine purges from initiate RTLS to post-landing + 15 minutes.

Assumed Hardware

1. 5-inch I. D. dump lines
2. Ambient helium storage (btl. vol. = 3,008 in^3, btl. wt. = 26.5 lb)
   - Initial conditions: P = 4000 psia, T = 540°R
   - Final conditions: P = 200 psia, T = 540°R
3. Cryo helium storage
   - Initial conditions: P = 3000 psia, T = 38°R
   - Final conditions: P = 200 psia, T = 38°R

	LH_2 Tank	LO_2 Tank
Initial liquid vapor pressure, psia	16	16
Dump pressure, psia	19	25
Helium for propellant dump, lb	22.3	13.3
Helium for repressurization, lb	3.3	Not req'd

MLI purge = 9.95 lb
Engine system purge = 3.64 lb
Total helium required = 52.5 lb
= (13) ambient helium bottles or 6 ft^3 cryo-storage bot les

OTV pressurization requirements were determined for both ambient storage and cryo-storage of helium. Although 13 helium bottles are needed for ambient storage, they will be Shuttle-mounted and not affect OTV performance. However, this particular vehicle-payload combination is length-limited within the cargo bay, and may not accommodate a large number of helium storage bottles. By comparison, cryo-storage of helium will not impact OTV design because only about 6 ft^3 of bottles are needed, which could be stored within the liquid hydrogen tank. Furthermore, this helium will also be available for the mission if abort is not required. A payload penalty due to excessive pressurization system weight will be incurred for the mission, however, because the cryo-storage system is designed for abort dump helium requirements rather than mission helium requirements.

Design details of an alternate abort dump pressurization system were defined. Instead of using ambient helium bottles, a helium bottle is installed inside the liquid hydrogen tank with an external hot gas heat exchanger using either hydrazine monopropellant or solid propellant as the heat source, exhausting overboard through the Orbiter skin. This results in a simplification of Shuttle accommodation system design. (See Figure 5-42.)

To supply heated helium at 22 psi for 5 minutes, a total weight (hot gas generator + heat exchanger) of ~90 lb has been determined. Hot gas flow rate is about 0.2 lb/sec.

Hamilton Standard has done similar work on a NASA/JSC CRAD for a freon/H_2 system for the Orbiter. A tube-in-tube, counterflow heat exchanger with N_2H_4 hot gas generation and throttling (demonstrated) configuration was defined.

5.2.4.4 Propellant Tank Conditions/Mission/Trade. The optimization analyses previously discussed to select the MLI requirements were for a baseline 8-burn mission (1000 lb_f engine). In this section the influence of number of burns and vehicle thrust level is examined. Four missions were used to determine final vapor residuals and maximum and minimum propellant tank pressure.

a. LO_2 Tank Conditions. Vapor residuals are given in Figure 5-43 as a function of initial liquid vapor pressure for each of the OTV missions identified in Table 5-8. It is evident that initial vapor pressure will have a substantially greater influence upon vapor residuals. The influence of engine thrust level or number of engine burns is virtually insignificant. The same conclusions can be drawn from Figure 5-43, which gives maximum and minimum tank pressures plotted as a function of initial liquid vapor pressure and mission parameters.

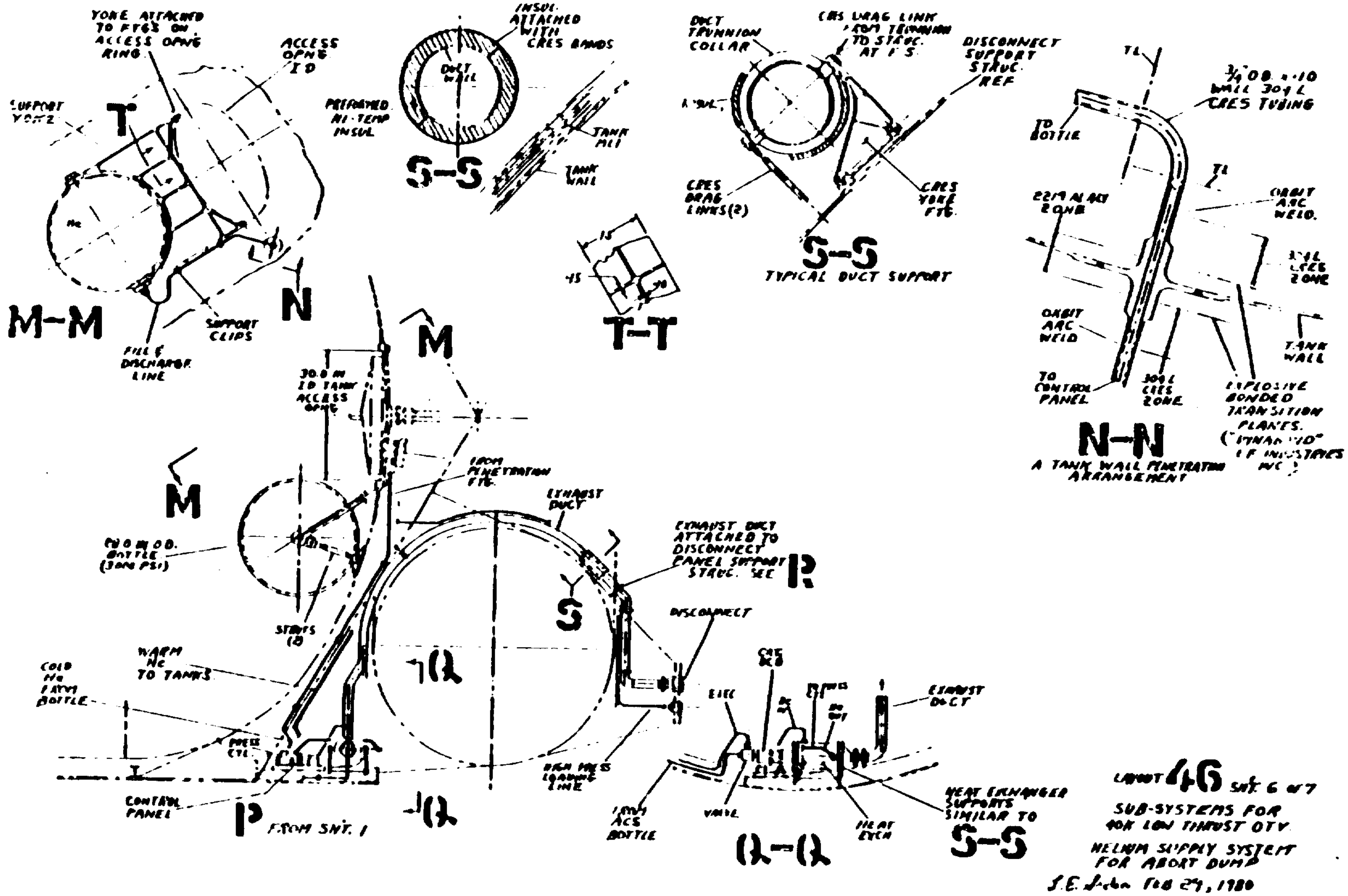


Figure 5-42. Helium supply system for abort dump.

b. <u>LH_2 Tank Conditions.</u> Hydrogen vapor residual and maximum tank pressure data are shown in Figure 5-44. Results are substantially the same as for the LO_2 tank. That is, the mission parameters identified in Table 5-8 will have a minimal influence upon vapor residuals and mission pressures. Minimum hydrogen tank pressures at MECO were not identified because autogenous pressurization can provide any pressure level at little or no cost or impact upon system design.

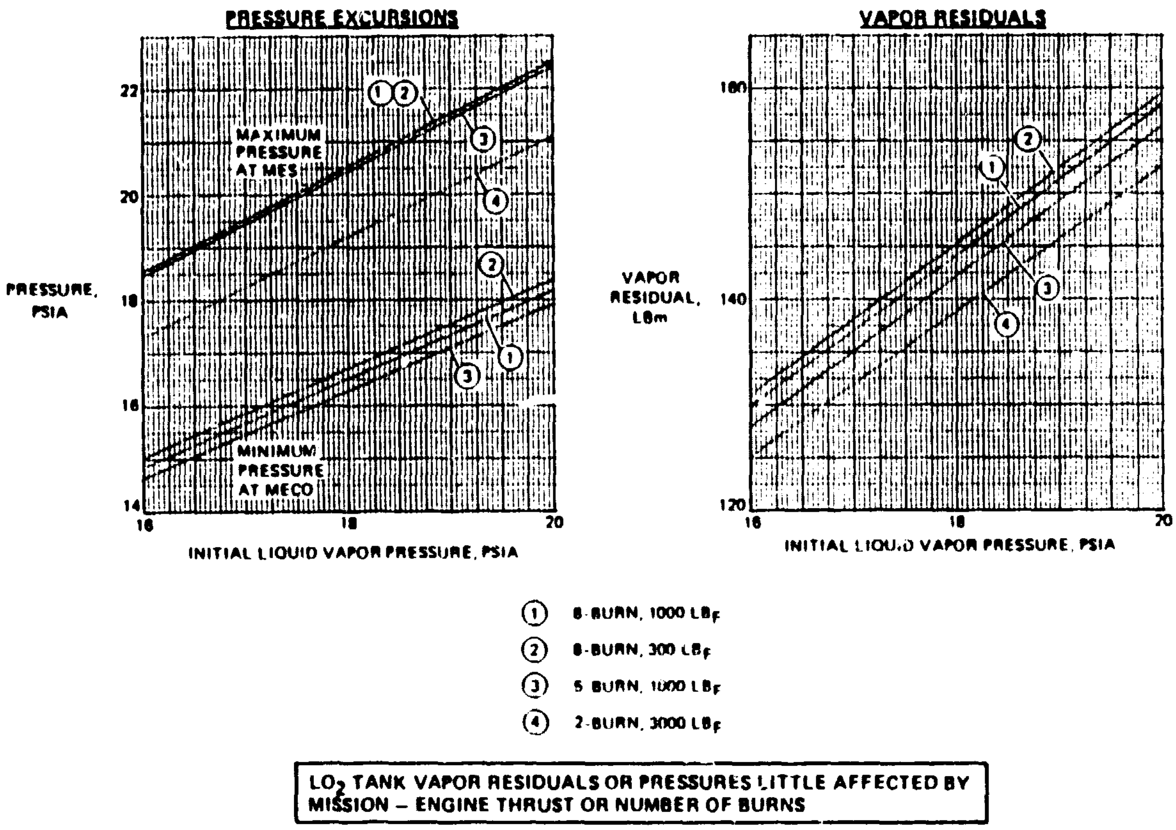
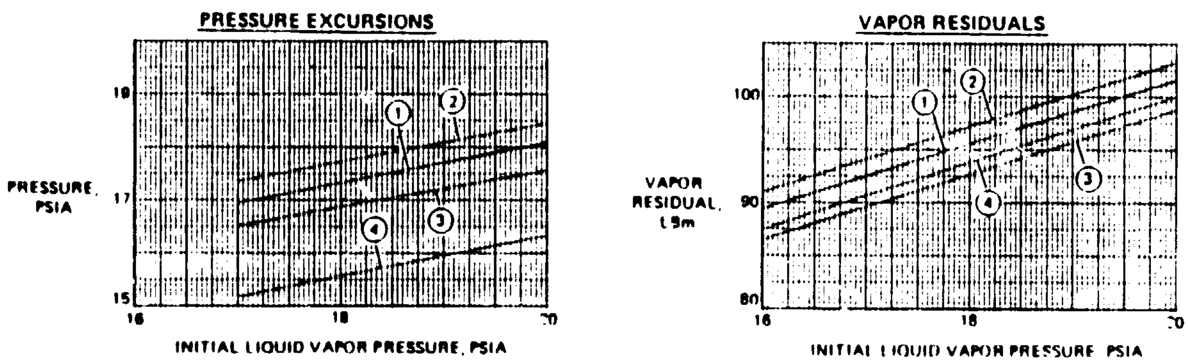


Figure 5-43. OTV mission parameters influence upon LO_2 tank.

Table 5-8. OTV mission transfer orbit parameters.

BASELINE

	Mission (1) 8-burn, 1000 lb_f		Mission (2) 8-burn, 300 lb_f		Mission (3) 5-burn, 1000 lb_f		Mission (4) 2-burn, 3000 lb_f	
Burn and Coast No.	Burn Time (hours)	Coast Time (hours)	Burn Time (hours)	Coast Time (hours)	Burn Time (hours)	Coast Time (hours)	Burn Time (hours)	Coast Time (hours)
1	0.43	1.3	1.43	1.3	0.79	2.7	1.15	5.0
2	0.41	1.5	1.37	1.5	0.79	2.7	0.46	—
3	0.40	1.8	1.33	1.8	0.79	2.7	—	—
4	0.43	2.3	0.43	2.3	0.79	2.7	—	—
5	0.46	3.0	1.53	3.0	1.34	—	—	—
6	0.50	4.7	1.67	4.7	—	—	—	—
7	0.54	4.4	1.80	4.4	—	—	—	—
8	1.34	—	4.47	—	—	—	—	—



TANK PRESSURE IS MAXIMUM VALUE TO OCCUR PRIOR TO HELIUM PRESSURIZATION

(1) 8 BURN, 1000 LB_F
(2) 8 BURN, 300 LB_F
(3) 5 BURN, 1000 LB_F
(4) 2 BURN, 3000 LB_F

LH_2 TANK VAPOR RESIDUALS OR PRESSURES LITTLE AFFECTED BY MISSION – ENGINE THRUST OR NUMBER OF BURNS

Figure 5-44. OTV mission parameters influence upon LH_2 tank.

5.2.5 ENGINE FEED DUCTS. Engine feed ducts for both fuel and oxidizer have axially restrained high flexure joints for absorbing the engine gimbal motions. Materials for both the flex joints and the ducts are 304L CRES, A286 CRES, and 718 Inconel. The fuel duct routes from a flanged outlet in the fuel tank access door to the engine inlet. The duct has an offset configuration using three flex joints. Future detailed analysis may show the need for a fourth flex joint.

The oxidizer feed duct consists of two sections. One section is an "elephant trunk" inside the tank, running from the acquisition ring to the tank wall. The second section is located outside the tank and is routed from a tank wall fitting to the engine inlet using a wrap-around configuration. Two flex joints are located in the gimbal plane and a third flex joint is located at the engine inlet. A fourth low-flexure joint is located at the tank wall to compensate for small angular misalignments.

5.2.6 FILL AND DRAIN. The fill and drain ducts for both tanks are separate from the abort dump systems. For the fuel tank, the circuit starts at a flanged outlet located off center in the access door. A shutoff valve is located at the outlet and a duct is routed from this valve to the disconnect panel located at the aft end of the oxidizer tank. The duct is 304 L CRES and incorporates three axially restrained low-flexure joints. The duct terminates at the disconnect panel through a disconnect fitting. During the fill or drain modes, the fuel does not flow through the acquisition device. The flow path is through the annulus area between the access door ring and the acquisition device.

The fill and drain for the oxidizer tank is similar to that described for the fuel, except the duct is short since the tank outlet is near the disconnect panel. This short duct section consists of three flex joints, two vaned mitered elbows, and a disconnect fitting. A shutoff valve is also provided at the outlet. Additional details and final location for the fill and drain are presented in the oxidizer tank design.

5.2.7 PROPELLANT UTILIZATION. The propellant utilization device is basically two concentric tubes insulated from each other and equipped with sensors and wiring over the entire length. A single straight section running from top to bottom inside the tank is desirable. For the fuel tank, however, a single straight section would have a span of 11.6 ft which presents support problems. The configuration has three straight sections positioned so that short support members from the tank wall can be used. A combination of support collars, drag links and one tongue/clevis connection at the aft end is used. This support system allows dimensional changes between the tank and the PU assembly. The wiring is routed through the tank wall at the aft bulkhead using a penetration fitting.

A straight bayonet-type PU assembly is used for the oxidizer tank. The assembly, complete with wiring, a blind flange, and one electrical penetration fitting is inserted through an access hole. The forward end mates with a conical fitting attached to the tank wall. The sliding fit between this conical fitting and the PU probe provides radial restraint only. The flanged connection at the aft end provides restraint in all directions. An alternate arrangement del :.s the blind flange by installing the PU through a tank access hole. Provisions for .his are shown in the LO_2 tank design.

5.2.8 <u>AUXILIARY PROPULSION/ATTITUDE CONTROL.</u> Four hydrazine attitude control modules are located between the fuel and LO_2 tanks and are supported from the main body structure. Each module consists of a spherical propellant tank and four thrusters arranged in a cluster. The thrusters are supported from the bottle and the nozzles are scarfed so that the exhausts do not protrude beyond the body structure. Each bottle has an acquisition device and a pair of external support trunnions. Propellant requirements are shown in Table 5-9 for an 8-burn mission.

Table 5-9. Low thrust OTV mission profile.

Event	Time (hr:min)	ΔV (ft/sec)	Approx. Weight	ACS Prop. Req. N_2-H_4 (lb)
Deploy OTV		10	58K	88
Coast #1	0:50			0.5
Burn #1	0:26			1.2
Coast #2	1:18		54K	0.8
Burn #2	0:25			1.1
Coast #3	1:30			0.9
Burn #3	0:24			1.1
Coast #4	1:48		51K	1.1
Burn #4	0:26			1.2
Coast #5	2:18			1.4
Burn #5	0:28			1.3
Coast #6	3:00			1.8
Burn #6	0:30			1.3
Coast #7	4:42			2.8
Burn #7	0:32			1.4
Coast #8	4:42			2.8
Burn #8	1:20			3.6
Deploy Payload		40		128
Coast #9	0:20			0.2
Burn #9	0:08			—
Coast #10	12:00			7.2
Burn #10	0:08			0.1
Rend. & Dock		15	6K	76
Total Impulse ≈75,000 lb-sec				323.8

5.2.9 AVIONICS/POWER. The low thrust expendable OTV has two operating characteristics which affect the avionics configuration. These characteristics are the longer transfer orbit duration and the reduced thrust acceleration and vibration as compared to a conventional thrust level expendable OTV.

The mission transfer orbit duration is increased from approximately 6 hours for Centaur, for example, to approximately 24 hours for a low-thrust OTV. The longer mission duration requires a means for maintaining the vehicle attitude reference accuracy and the guidance accuracy. An attitude update from a star tracker can satisfy the attitude reference accuracy. For the known mission guidance accuracy requirements, an attitude reference update by a star tracker will suffice in meeting the guidance accuracy requirements. For missions with unknown, more stringent guidance tolerances, a guidance update could be obtained from a TDRSS or GPS transponder yielding range and range rate updates.

A long transfer orbit results in increased radiation exposure in the Van Allen Belt. For a single-trip, expendable OTV with low integrated total dosage, this is not a severe design requirement.

The electrical power system has to have a long-term energy source. As will be shown in the detail of the Electrical Power System discussion, a fuel cell system has the highest energy per unit mass yield for missions in the 10- to 100-hour duration class. This includes dual redundance for the fuel cell. A standard thrust OTV also has some mission durations in this range, so the EPS for both low and standard thrust OTV could use fuel cells, with higher reactant tankage requirements for the low thrust OTV.

The extended duration low thrust OTV mission implies the need for higher avionics reliability. This, along with the increased ability to add redundancy without excessive weight penalty due to integrated circuit state-of-the-art advances, leads to an OTV avionics using advanced redundancy techniques and distributed processing.

The reduced thrust acceleration and vibration levels are of significance primarily for items that may be deployed during the transfer orbit such as solar arrays and antennas. The EPS will not have solar arrays for the standard missions, and deployable antennas are part of the payloads, so the OTV avionics will not be influenced by this design relaxation.

A representative OTV avionics configration is shown in Figure 5-45. Maintenance of high reliability for long durations can be met with advanced redundancy techniques using fault-tolerant computers with: power supply and logic cross strapping; memory bank sparing; improved self test, error detection, and soft failure detection algorithms; and increased component and sensor redundancy. Illustration of reliability improvement from these techniques is given in Figure 5-46. The advent of the micro-processor era and optical data transmission facilitates distributed computer architecture with

improved performance, simpler segregated software, lightweight componentry and harnessing, high EMI tolerance, and theoretical optical data rate limit. Many functions previously performed by analog circuitry or special purpose digital logic will now be accomplished by micro-processors. A Charged Coupled Device type of star tracker provides improved false star discrimination. If accurate navigation update is needed, the transponder can be a TDRSS unit with ranging, or a special GPS unit can be added, assuming GPS operation is extended out to GEO. A weight and power summary of a typical low thrust expendable OTV avionics configuration is presented in Table 5-10.

In Figure 5-47, a comparison is made of three power source alternatives (i.e., battery, solar array, and fuel cell), with regard to minimum weight for various power levels and mission durations. The fuel cells use propellant grade fuel with the tank weight assigned to propulsion. Fuel cells in a dual configuration have a margin over solar array source for 1 kW systems in the 10- to 100-hour mission duration. In addition, fuel cells do not have the solar orientation and thrust acceleration operating constraints of solar arrays.

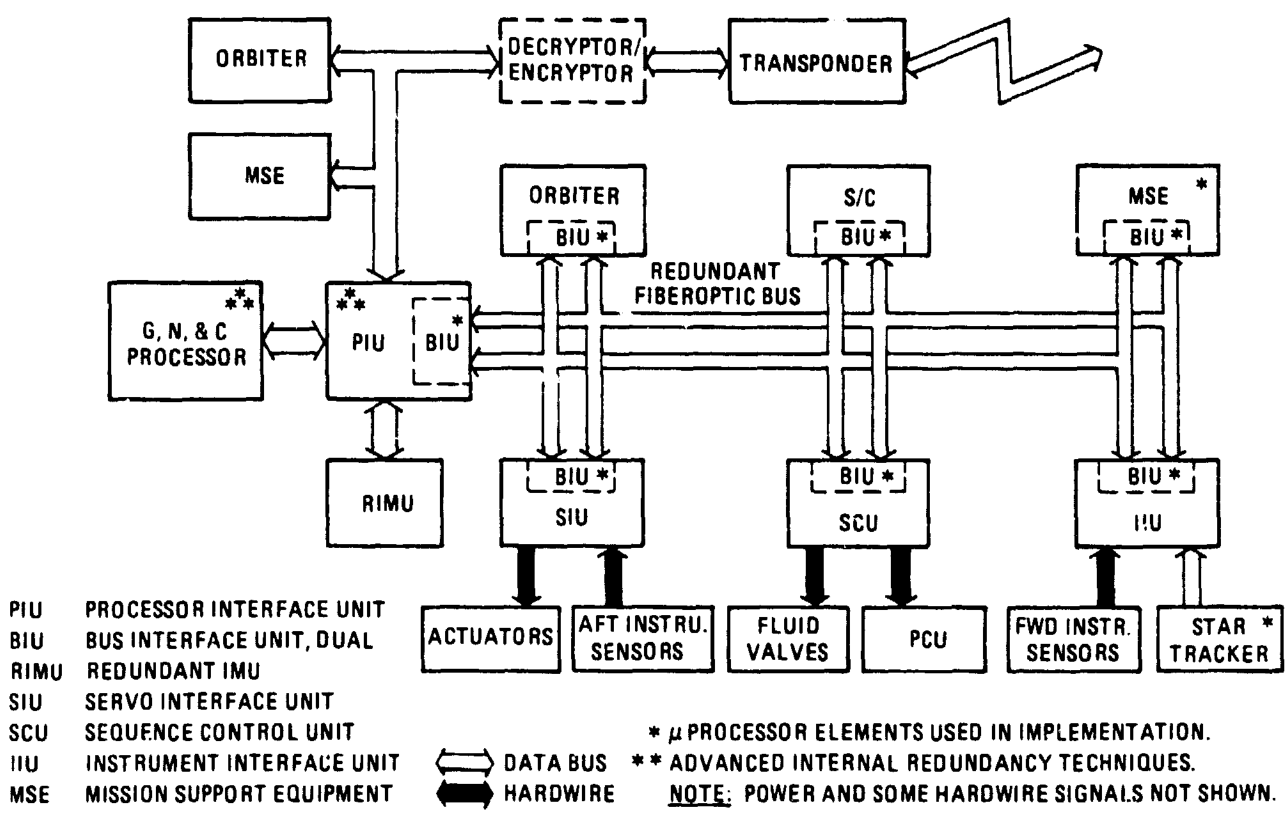


Figure 5-45. Data buses and advanced redundancy techniques.

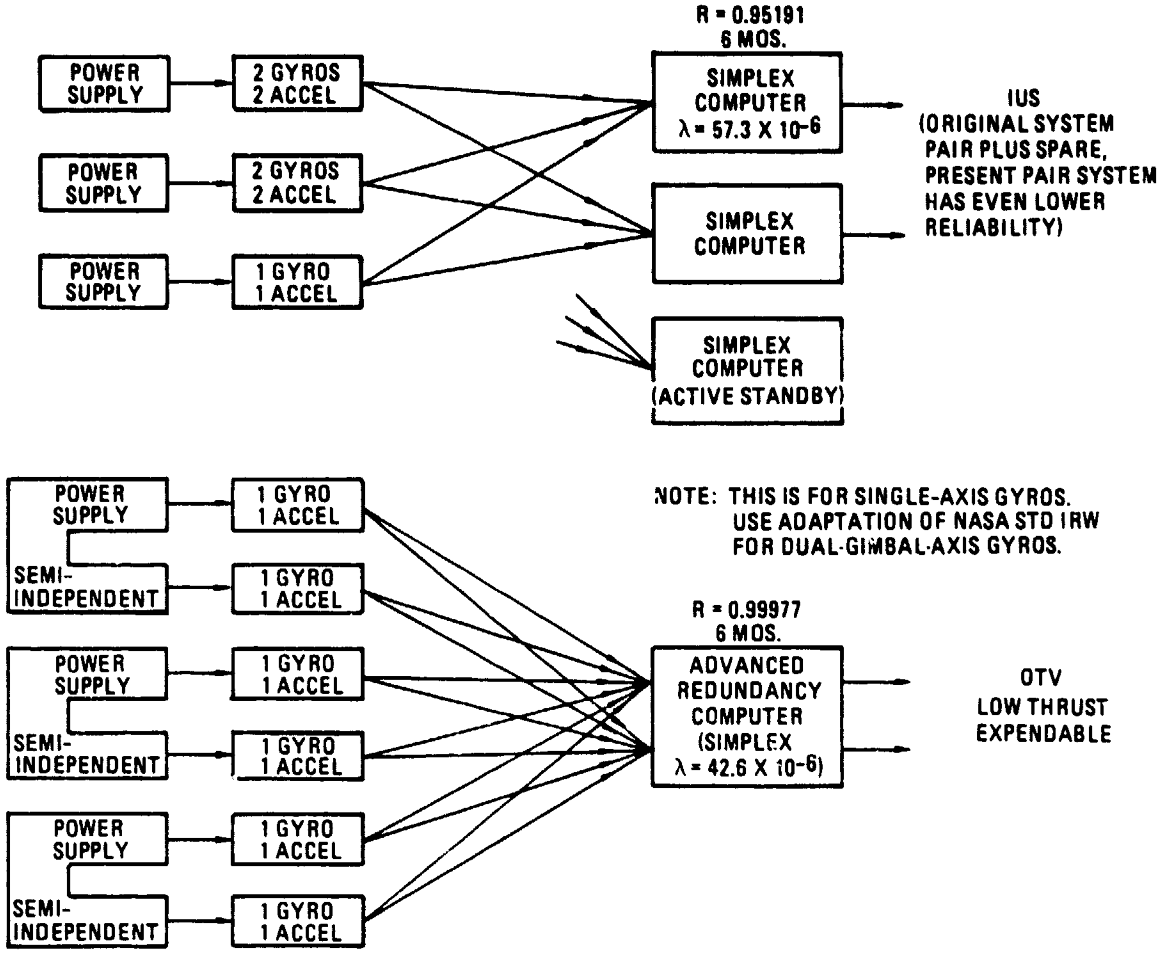


Figure 5-46. Enhanced reliability for OTV.

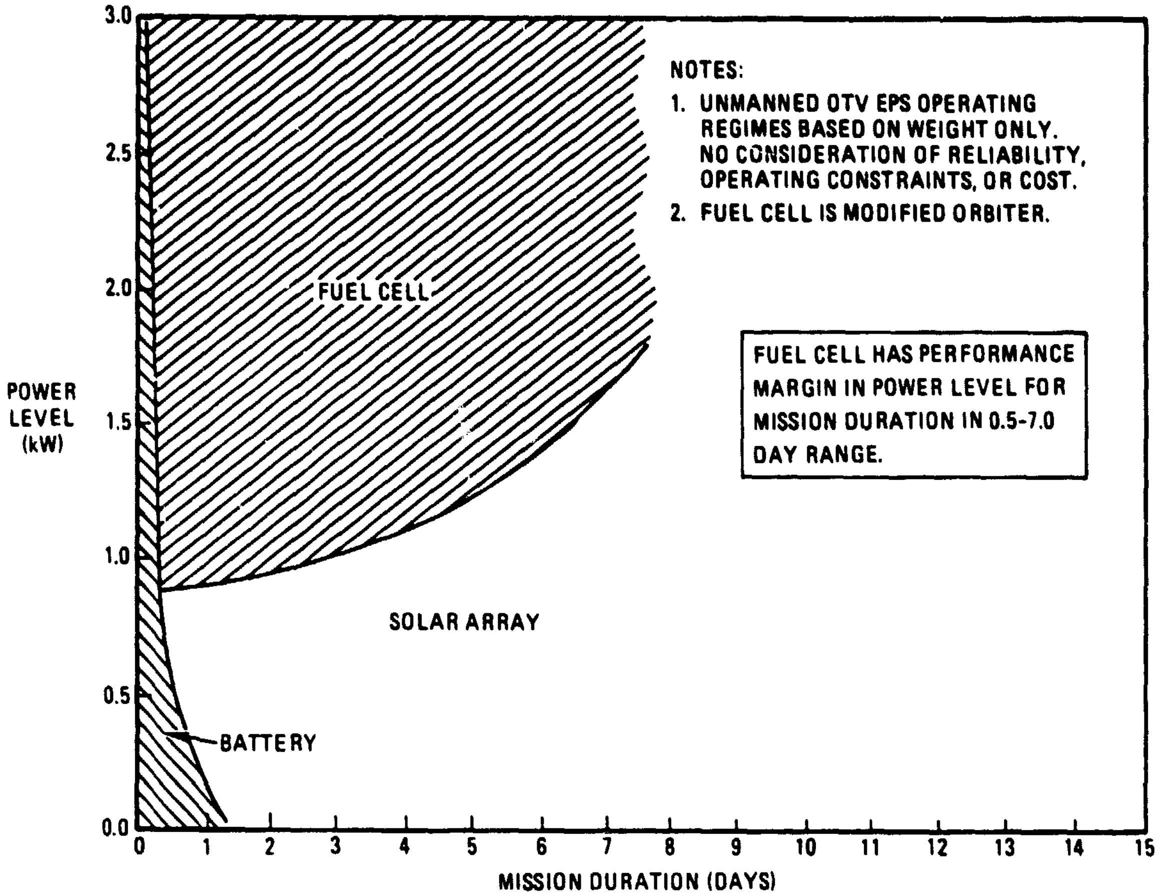


Figure 5-47. Power/mass efficiency operating regimes for various power sources.

Table 5-10. Low-thrust OTV avionics weight and power summary.

	Weight (kg)	Power (W)
ACS		
RDMU, 6 channel	33.0	215
CCD Star Tracker, Dual	8.4	52
Sun Sensor, Dual	2.2	5
RCS	(covered by propulsion)	10
Bus Interface, Dual	4.5	10
	48.1	292
T, T, &C		
TDRSS Transponder, Dual	15.0	60
Premod Processor, Dual	3.6	10
Hemispherical Antennas	0.2	—
RF Hardware	1.4	—
	20.2	70
G, N, &C Processing		
G&N Processor Int., Redundant	16.8	71
Processor Interface Unit Int., Redund.	3.4	15
	20.2	86
Servo Electronics		
Servo Interface Int., Redundant	9.1	20
Bus Interface, Dual	4.5	10
	13.6	30
Sequence and Pyro Control		
Sequence Control Int., Redundant	26.8	20
Pyrotechnic Control Int., Redundant	14.5	20
Bus Interface, Dual	4.5	10
	45.8	50
Instrumentation (Additional)		
Signal Conditioning	8.2	10
Transducers	9.1	—
Bus Interface, Dual	4.5	10
	21.8	20
DOD Communications		
Decryptor/Encryptor	5.0	10

Table 5-10. Low-thrust OTV avionics weight and power summary. (Concluded)

		Weight (kg)	Power (W)
Propulsion			
Switching Modules	(allocated SCU)		20
Vent Valves	(allocated Fluidics)		200
Hydrazine Heaters	(allocated Propulsion)		50
			270
Orbiter Interface			
Harnessing and Connectors		2.0	
Bus Interface, Dual		4.5	10
(Fluidic and Propulsion Allocated to those Subsystems)			
		6.5	10
SUBTOTAL TO POWER SYSTEM		181.2	838
Power			
Fuel Cell System, Dual		86.0	—
(Including Transient Battery)		0.34 kg/hr	—
Power Control		6.8	10
Power Harnessing		2.5	—
Bus Interface, Dual		4.5	10
		99.8 +0.34 kg/hr	20
VEHICLE TOTALS		281 +0.34 kg/hr	858

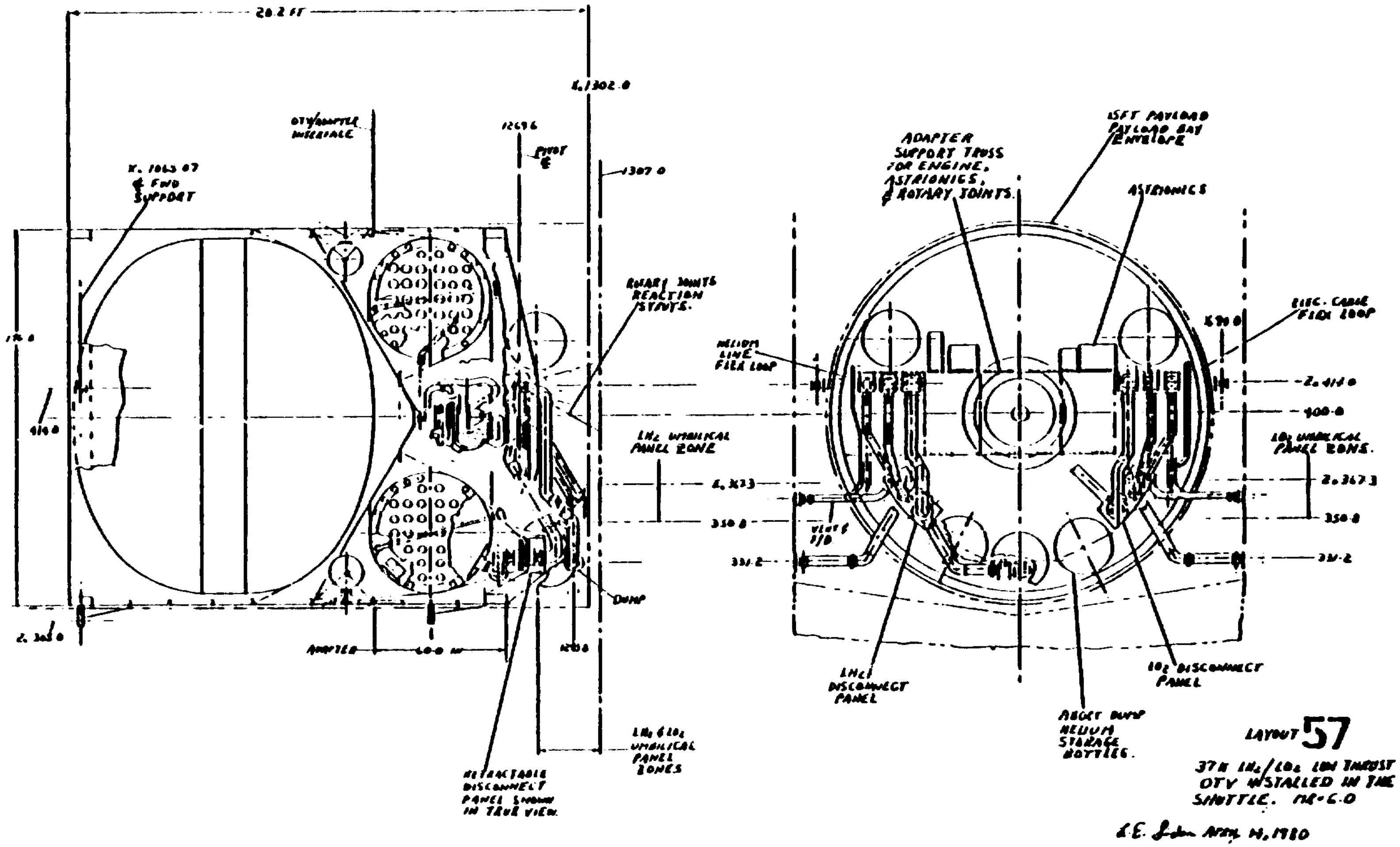
5.3 INSTALLATION IN SHUTTLE. The forward end of the OTV is supported at X_o 1065.07 from a pair of trunnion fittings and a keel fitting which are integral with the OTV body structure. The aft end is supported from a rotary adapter which interfaces with a frame on the OTV and structurally connected with a system of latches.

The purpose for the adapter is to provide structural support, provisions for abort dump, systems interfaces with the Shuttle, and deployment of the OTV. The adapter is a cylindrical structure having one primary box frame, one interface ring (with latches), three stabilizing rings, one truss-type crossover structure, and a pair of disconnect panels. The adapter is also equipped with helium storage bottles for abort dump, astrionics equipment, and plumbing which runs from the disconnect panel to the Shuttle interfaces.

5.3.1 Adapter Structure. The primary box frame is equipped with two trunnion fittings which interface with Shuttle at X_o 1269.6. A keel fitting is also provided forward of this box frame. The truss-type crossover structure spans the adapter diameter and provides support for the engine, the plumbing rotary joints, astrionics equipment, and serves as a structural tie between the primary support point areas. The two disconnect panels (one for LH_2 and one for LO_2) are supported from the box ring with a system of struts. These panels are mounted on a rail or linkage system which permits retraction from the mating OTV panels.

5.3.2 Helium Storage. The ambient helium storage bottles provide gas to the OTV propellant tanks during abort dump. These high pressure bottles (4500 psi) are supported from the aft side of the primary box frame with yokes and struts. The bottles are interconnected with tubing through a control system. Three bottles are located between the disconnect panels at the bottom area and two are positioned above the pivot centerline near the plumbing rotary joints.

5.3.3 Plumbing. The plumbing system provides overboard circuits for ground vents, flight vents, fill and drain, helium fill, helium purge, and abort dump (Figure 5-48). There are six duct assemblies and two tubular lines. Each duct assembly has two sections. The first section runs from the disconnect panel to a rotary joint and the second section routs from the rotary joint to the overboard interface. A typical duct is a 304L CRES welded assembly containing three axially restrained flex joints, a flange at one end, and a disconnect half at the opposite end. The flanges and disconnects are designed for dual seals with cavities vented overboard. The ducts for fill, drain, and ground vent are routed overboard through umbilical panels located between Z_o 367.3/Z_o 350.8 and X_o 1307/X_o 1278.0. The abort dump ducts have overboard locations at Z_o 331.9 and X_o 1295.0. The flight vent and electrical cables attach to the Shuttle service panels located at the 1307 bulkhead.



ALL SHUTTLE INTERFACES HAVE BEEN DEFINED FROM GDC/LeRC "CENTAUR-IN-SHUTTLE" STUDIES.

Figure 5-48. Low thrust OTV interfaces.

To accommodate deployment, rotary joints are used. These joints are mounted on the adapter crossover structure and feature dual seals with vented cavities routed overboard. The static sections of these joints are attached to the 1307 bulkhead with struts for reacting the breakout forces. The two helium supply lines and the electrical cables use flex loops to absorb adapter rotation.

5.3.4 Deployment. The OTV and adapter can be rotated to 30° and 75° positions. (Figure 5-49). The 30° position is the minimum for clearing the OTV and payload package from the Shuttle. This 30° position is also limited by the adapter box ring and the helium bottles. Some payloads are deployed before the OTV is released from the adapter, therefore, the 75° position may be required, which, in turn, reduces the available payload length. For the 75° position, the pivot center is moved forward to X_0 1230.3 which is one of the standard locations. The relation between available payload length and deployment angle is, therefore, influenced by available support points.

During normal landings and abort operations, the center of gravity must fall within specified envelopes. Out-of-envelope conditions are permissible during launch and space flight. However, the conditions must be correctable before reentry or in the event of an abort on launch. The baseline OTV and payloads satisfy these requirements. (See Figure 5-50.)

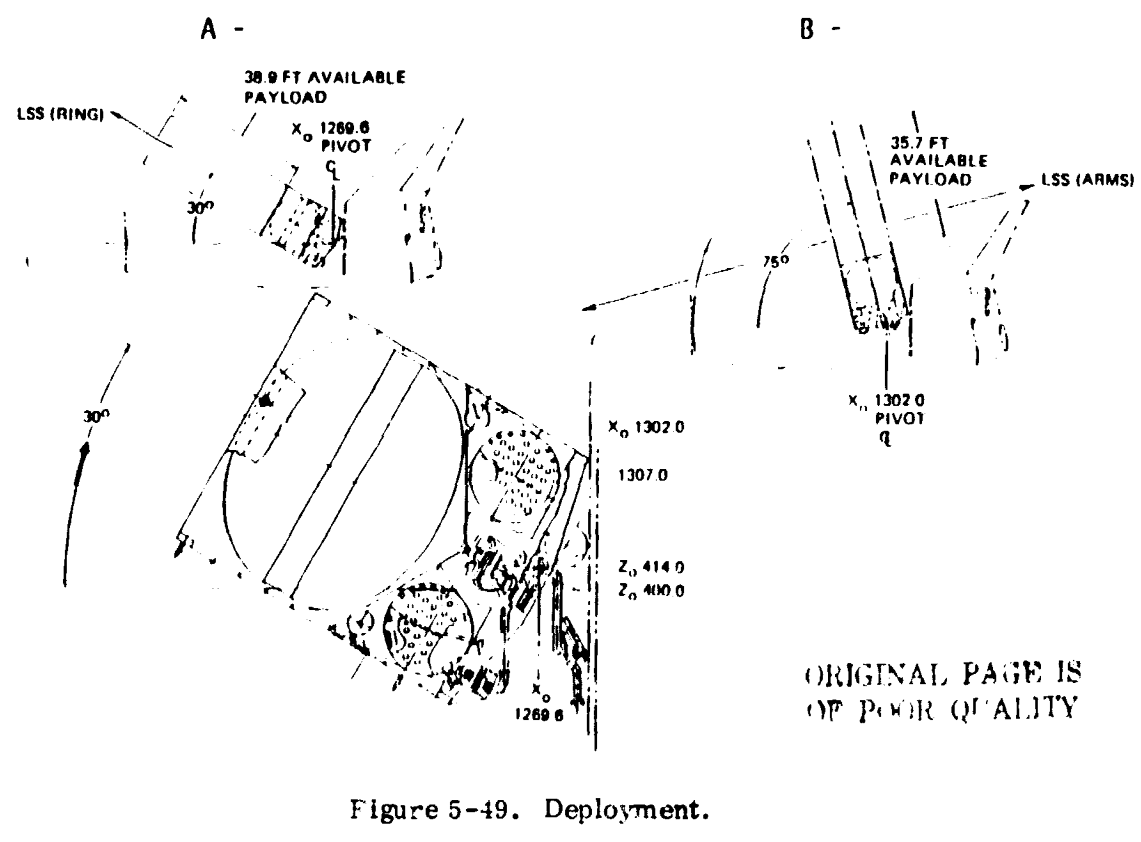


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Figure 5-49. Deployment.

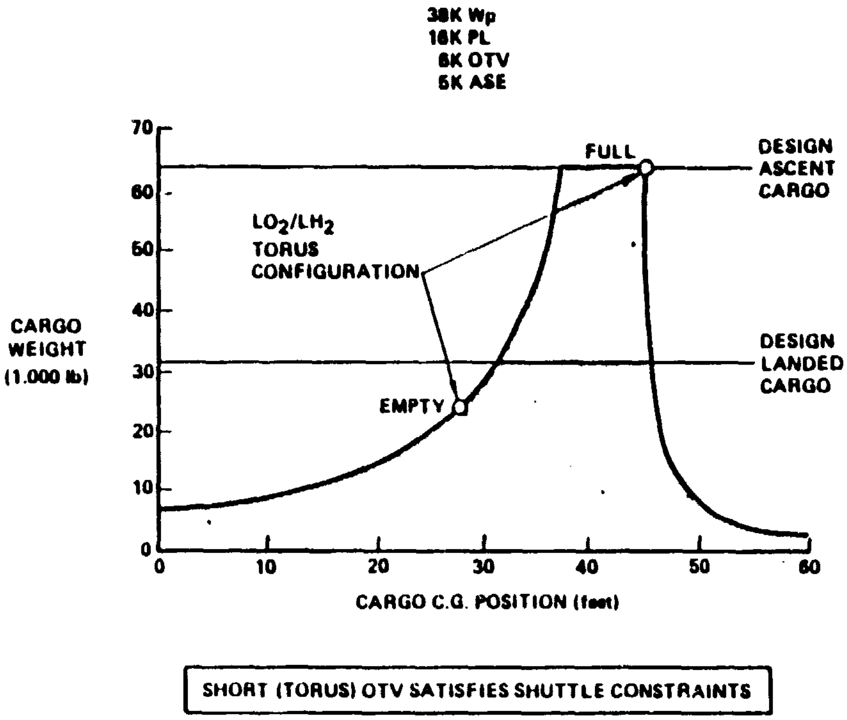


Figure 5-50. Shuttle c.g.

6

PROPULSION/SUBSYSTEM TECHNOLOGY REQUIREMENTS

Systems identified in the baseline concept that require technology development are the engine, the torus LO_2 tank, the propellant acquisition system for the torus tank, and the insulation system for the torus tank. These are described in standard SRT format at the end of this section.

Estimated investment needed is:

Torus tank	\$3 to 5 M	Fabrication and Test
Propellant acquisition	\$1.0 M	Fabrication and Test
Insulation	\$0.5 M	Fabrication and Test
Low thrust engine	\$3 to 7 M	Both new low thrust and pumped idle
TOTAL	\$7.5 to 13.5 M	

6.1 TORUS TANK

The United States has no large torus tank space applications (France and Russia do: Ariane, Soyuz, Cosmos, Zond); however, Convair has built torus tanks to evaluate individual technologies (sloshing, residuals, and manufacturing, Figures 6-1 and 6-2) but a complete system development is required to determine the interaction of each technology, as follows:

a. Design
   - Optimization
   - Structural support
   - Manufacturing/producibility/forming/welding/assembly
   - Component assembly/installation/checkout

b. Sloshing
   - Control/c.g.
   - Baffles

c. Propellant (LO_2) Acquisition/Residuals
   - Offset c.g.
   - Thrust transient
   - Low flow/high flow
   - Zero-g

d. <u>Pressurization</u>
- Main engine operation/multiple burns
- Abort dump

e. <u>Insulation</u>
- MLI applied to torus shape/efficiency vs. conventional tanks
- Purge

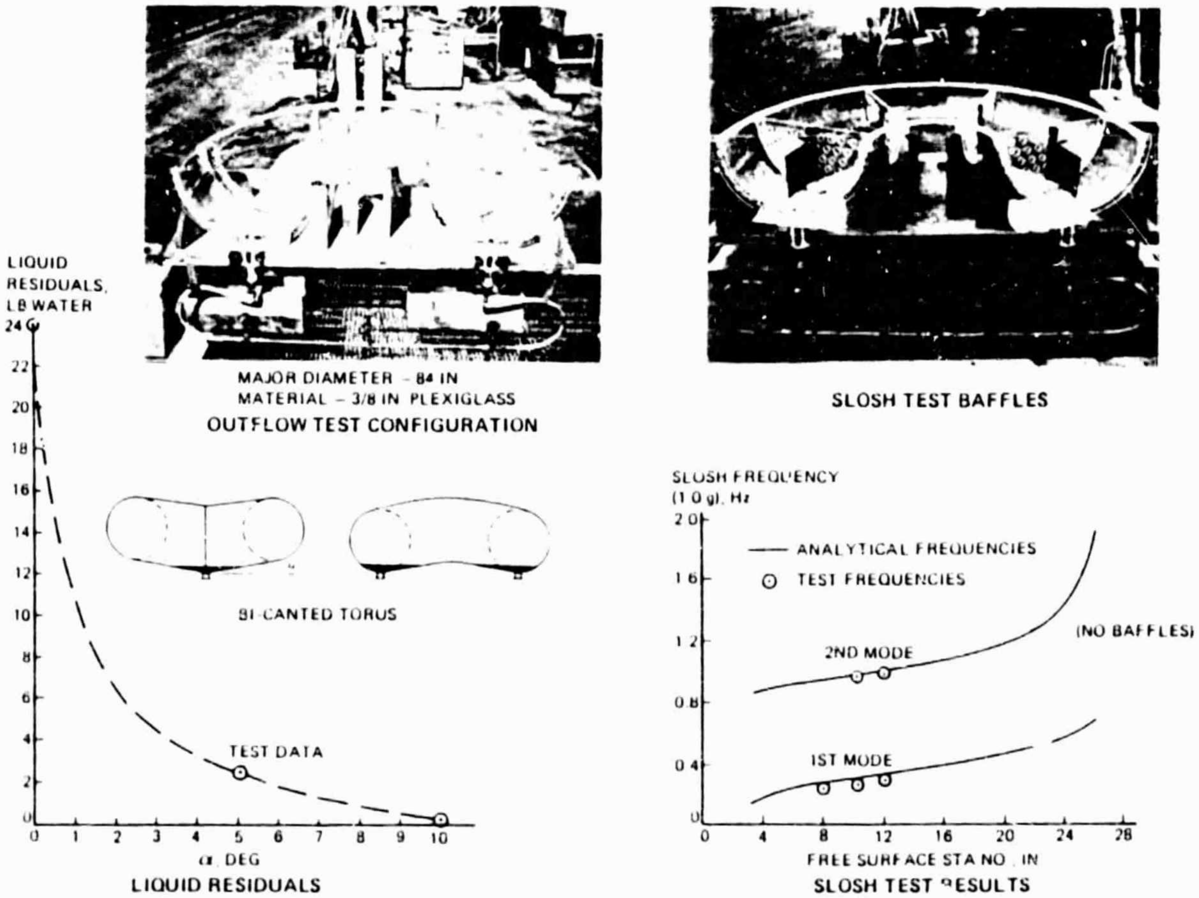
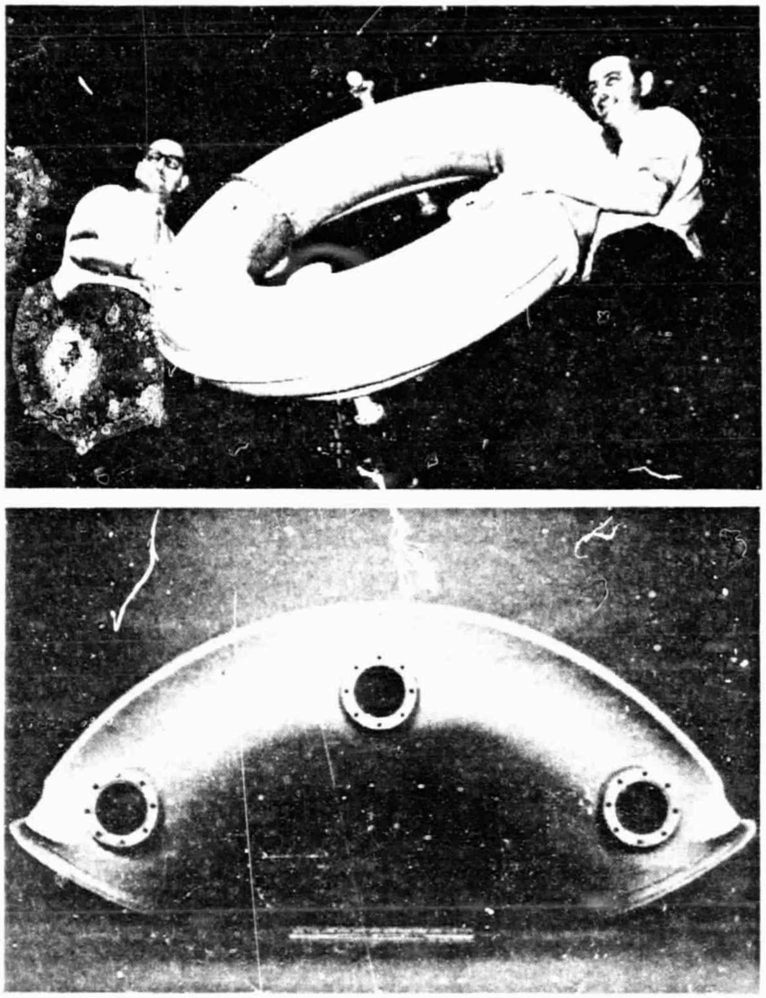


Figure 6-1. Torus tank tests (Ref. AIAA 70-1325).



THIN WALL – ALUMINUM CRYOGENIC TORUS TANKS HAVE BEEN BUILT BY GDC

Figure 6-2. Aluminum torus tank.

6.2 LOW THRUST ENGINE

The United States has no high performance, low thrust hydrogen-oxygen space engine. Studies currently being sponsored by NASA/LeRC and NASA MSFC are investigating two concepts. Technology development/demonstration is recommended.

a. New Low Thrust Engine. This concept being studied by NASA/LeRC represents an optimized engine, specifically designed for low thrust application. Its advantages are its small size and low weight. Technology development concerns are cooling, very small pumps, and performance.

b. Pumped Idle/OTV Engine. The OTV engine concepts being studied by NASA MSFC include the option of operating at reduced thrust (10%). Its advantage is common development/utilization in the OTV mission model for high thrust missions. Technology concerns are performance and stability at 10% thrust. The engine is also larger and heavier than a new low thrust engine.

DEFINITION OF TECHNOLOGY REQUIREMENT

1. TECHNOLOGY REQUIREMENT (TITLE): Torus Tank

2. TECHNOLOGY CATEGORY: Low Thrust OTV

3. OBJECTIVE/ADVANCEMENT REQUIRED: Integrated System

4. CURRENT STATE OF ART: Convair has built torus tanks for evaluation. France and Russia have large torus space applications.

5. DESCRIPTION OF TECHNOLOGY: Short OTVs are needed if accompanying large payloads are to be transported in the space shuttle orbiter. The shortest stage is achieved with a torus LO_2 tank surrounding the engine. Development of a full scale flight weight aluminum alloy toroidal tank for long term cryogenic storage for space application has never been done. Internal baffle systems, acquisition devices, supports arrangement (low conductive struts), and access openings are necessary complications.

6. RATIONALE AND ANALYSIS: The torus is a required configuration for aerospace vehicles for efficient use of available volume determined by the shuttle payload bay restraints. The torus yields the shortest OTV stage which in turn increases the available length for payloads.

DEFINITION OF TECHNOLOGY REQUIREMENT

1. TECHNOLOGY REQUIREMENT (TITLE): Torus Tank **Page 2 of 3**

7. TECHNOLOGY OPTIONS: Various cross sectional shapes such as circular, kidney (tension membranes), and elliptical.

8. TECHNICAL PROBLEMS: Construction and assembly of gores (membrane forming and joining). Minimize residuals and sloshing. Numerous penetrations in shell necessary for acquisition system, outboard and inboard supports, abort dump, vent, etc.

9. POTENTIAL ALTERNATIVES: Nested tanks which result in a longer stage and present structural penalties associated with the compressive bulkhead.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT.

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT No.

1. TECHNOLOGY REQUIREMENT (TITLE): Torus Tank Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

SCHEDULE ITEM	CALENDAR YEAR																	
	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	
TECHNOLOGY Adapt current toroidal tank technology to low thrust OTV. 1. Develop mfg techniques, analyze structural and fluid characteristics. 2. Fabricate test tank and perform evaluation tests																		
FUNDING LEVEL (Millions 1980 $)			0.5	1.5	2.0													

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE					X													TOTAL
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard-tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-52

DEFINITION OF TECHNOLOGY REQUIREMENT

1. **TECHNOLOGY REQUIREMENT (TITLE):** Acquisition Device for Torus Tank — Page 1 of 3

2. **TECHNOLOGY CATEGORY:** Low Thrust OTV

3. **OBJECTIVE/ADVANCEMENT REQUIRED:** Cryogenic propellant management under low g

4. **CURRENT STATE OF ART:** Testing of cryogenic capillary devices performed under NAS3-20092 and planned under NAS8-31778

5. **DESCRIPTION OF TECHNOLOGY:** Acquisition systems are required to assure liquid propellant flow to engine feed lines during engine operation. The system chosen is a tubular ring manifold at the bottom of the toroidal tank with screened branch channels positioned inside small sumps. A single outflow line supplies propellant to the engine. The screened branch channels prevent vapor from entering the device under most conditions due to surface tension effects. Vapor may not be allowed in the device due to large vapor head trapped under low accelerations.

6. **RATIONALE AND ANALYSIS:** Because it can acquire propellants in any part of the tank, the acquisition system chosen will significantly reduce liquid residuals in the toroidal tank should a thrust misalignment occur during final draining. It will also reduce residuals due to rather severe propellant suction dip which occurs under low accelerations.

DEFINITION OF TECHNOLOGY REQUIREMENT

1. TECHNOLOGY REQUIREMENT (TITLE): Acquisition Device for Torus Tanks Page 2 of 3

7. TECHNOLOGY OPTIONS:

a. Develop full-scale acquisition system as presently conceptualized.
b. Analyze a continuous screened ring with no branch channels.

8. TECHNICAL PROBLEMS:

a. Suction dip for flow up into channel not well studied.
b. Mechanism of screen breakdown in a heating environment not well understood.
c. Startup and shutdown transients flow tests required (NAS8-31778 should provide some data).

9. POTENTIAL ALTERNATIVES:

Propulsive settling only with multiple outlets.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT.

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT

No.

1. TECHNOLOGY REQUIREMENT (TITLE): Acquisition Device/Torus

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
1. Analyze fluid flow mechanics & develop fabricate test components to demonstrate characteristics.																			
2. System test torus																			
FUNDING LEVEL (Millions 80 $)			0.5	0.5															

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE				X														
NUMBER OF LAUNCHES																		

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard-tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

3652-98

DEFINITION OF TECHNOLOGY REQUIREMENT

1. TECHNOLOGY REQUIREMENT (TITLE): Insulation/Torus Tank Page 1 of 3

2. TECHNOLOGY CATEGORY: Low Thrust OTV

3. OBJECTIVE/ADVANCEMENT REQUIRED: Complete thermal insulation at minimal weight to assure liquid at all times and minimize propellant loss due to boiloff.

4. CURRENT STATE OF ART: MLI has been successfully applied to more conventional geometries, but not the torus.

5. DESCRIPTION OF TECHNOLOGY: Multilayer insulation (MLI) consisting of radiation shields, separated by low conductive spacers are required for upper stage vehicles to provide thermal protection of the cryogenic propellant tanks. The insulation system must be capable of providing adequate performance for the required mission cycles including ground operations (to prevent moisture condensation), launch, be compatible with the torus tank design and the structural environment to which it is exposed, such as structural bending, flexing and buckling resulting from thermal stresses and launch acceleration, vibration, and acoustic loading.

6. RATIONALE AND ANALYSIS: There are MLI system designs available, together with analytical and experimental results. These systems include: (1) double goldized Kapton and double coated aluminized Kapton radiation shields, separated by Dacron tufts, utilizing purge bag and purge/repressurization systems; (2) double aluminized Mylar shields with silk and Dacron net spacers, utilizing a helium diffusion system (no purge bag). None of these systems has been applied to a torus tank. Specific requirements for the torus tank are: (1) to establish thermally efficient MLI design concept; (2) develop an efficient, lightweight MLI purge concept; and (3) establish thermal performance data.

DEFINITION OF TECHNOLOGY REQUIREMENT

1. TECHNOLOGY REQUIREMENT (TITLE): Insulation/Torus Tank

7. TECHNOLOGY OPTIONS:

1. Use purged, high performance, moisture resistant, coated MLI.
2. Consider MLI/foam composites to reduce prelaunch heat flux.
3. Consider MLI with one or two vapor cooled shields within a double wall tank to reduce boiloff such, that little or no venting will be required for short term missions. Disadvantages are high cost, high weight, and difficulties to construct lightweight double wall dewars.

8. TECHNICAL PROBLEMS:

1. Effective purging of MLI requires a purge enclosure and purging hardware which is expensive and heavy.
2. Radiation shield materials must have the ability to withstand exposure to a humid environment.
3. Complexity of MLI blanket fabrication due to the severe curvature of the torus tank.

9. POTENTIAL ALTERNATIVES:

1. MLI with coated double aluminized Kapton radiation shields, separated by Dacron tufts, utilizing a purge and repressurization system (with purge bag).
2. MLI with coated double aluminized Kapton radiation shields with Dacron net spacers (no purge bag).

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT.

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT — No.

1. TECHNOLOGY REQUIREMENT (TITLE): Insulation/Torus Tank — Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95		
TECHNOLOGY																			
1. MLI design & fabrication																			
2. Thermal performance & purge test																			
3 System test torus																			
FUNDING LEVEL (Millions of 1980 dollars)			0.2	0.3															

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE				X													TOTAL
NUMBER OF LAUNCHES																	

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard-tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

8652-62

DEFINITION OF TECHNOLOGY REQUIREMENT

1. TECHNOLOGY REQUIREMENT (TITLE): Low Thrust Engine

2. TECHNOLOGY CATEGORY: Low Thrust OTV

3. OBJECTIVE/ADVANCEMENT REQUIRED: Low Thrust (1 - 3 K) High Isp (450 sec) Engine

4. CURRENT STATE OF ART: No high performance low thrust engine exists

5. DESCRIPTION OF TECHNOLOGY: Many of the large space systems which have been identified as candidates for transportation to GEO have minimum capability to withstand transfer acceleration loads. The development of a low thrust engine in the 1- to 3-K range is required. The engine must be of high performance and be capable of multiple burns.

6. RATIONALE AND ANALYSIS: The low thrust engine options include a new low thrust design, or pumped idle mode of a larger (15K) OTV engine. While a pumped idle mode derivative engine could have lower (Δ) development costs, a new low thrust engine has advantages in weight, size, design simplicity, performance, and lower recurring cost.

DEFINITION OF TECHNOLOGY REQUIREMENT

1. TECHNOLOGY REQUIREMENT (TITLE): Low Thrust Engine

7. TECHNOLOGY OPTIONS:

New low thrust engine

Pumped idle OTV derivative engine

8. TECHNICAL PROBLEMS:

1. Small engine technology (cooling, pumps)
2. Pumped idle technology (stability)
3. Multiple starts (2-9 burns)

9. POTENTIAL ALTERNATIVES:

a. New low thrust engine.
b. Low thrust (pumped idle mode) of larger engine.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT

No.

1. TECHNOLOGY REQUIREMENT (TITLE): Low Thrust Engine

Page 3 of 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

SCHEDULE ITEM	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	
TECHNOLOGY																		
Small Engine Technology Development			▬	▬	▬													
Pumped Idle Technology for RL10			▬	▬														
FUNDING LEVEL (Millions 1980 dollars)																		
Small Engine Technology			1.0	1.0	0.5													
Pumped Idle Technology for RL10			0.5	0.5														

13. USAGE SCHEDULE:

																	TOTAL
TECHNOLOGY NEED DATE					X												
NUMBER OF LAUNCHES																	

14. REFERENCES

15. LEVEL OF STATE OF THE ART:

1. Basic phenomena observed and reported
2. Theory formulated to describe phenomena
3. Theory tested by physical experiment or mathematical model
4. Pertinent functions or characteristic demonstrated, e.g., material, component
5. Component or breadboard-tested in relevant environment in laboratory
6. Model tested in aircraft environment
7. Model tested in space environment
8. New capability derived from a much lesser operational model
9. Reliability upgrading of an operational model
10. Lifetime extension of an operational model

1652 62

7

COSTS AND SCHEDULE ESTIMATES

The purpose of this task was to estimate the costs of the low thrust OTV and provide a program schedule for development, production, and operation of the vehicle.

7.1 COST METHODOLOGY

The low thrust OTV costs were determined using the General Dynamics Orbital Transfer Vehicle (OTV) computerized cost model. The model was developed under NASA/MSFC Contract NAS8-33533, "Orbital Transfer Vehicle Concept Definition Study." The model is presented in detail in the final report of that study. Its basis is primarily from the General Dynamics Space Tug Cost Model and the Space Systems Life Cycle Cost Model. The OTV cost model is computerized for quick turnaround with an output format which follows the work breakdown structure (WBS).

The organization of the cost model is centered around the WBS, with a cost estimating relationship for each WBS element. A summary WBS is shown in Figure 7-1. More detailed breakouts of the cost elements are provided in Figures 7-2, 7-3, 7-4, and 7-5. OTV hardware is presented at a Level 5 for maximum cost visibility of the vehicle system. The WBS numbering system is as follows:

WBS Number Series	Cost Element
1000	DDT&E phase
2000	Production phase
3000	Operations phase
4000	First unit cost

The OTV cost model is a parametric costing technique. The parametric cost estimating relationships (CERs) for the individual cost elements were determined through analysis of historical cost data and cost study results. Cost estimating relationships for hardware provide cost as a function of the most influential parameter in the system, such as weight, thrust, or power. Other relationships, such as the cost for command and control in the operations phase, are price-quantity relationships. Given the size of ground crew, the model computes the total crew cost.

7.2 GROUNDRULES/ASSUMPTIONS

1. Costs are expressed in 1979 dollars.

2. Contractor fee is excluded.

3. All low thrust OTVs are expendable. Twenty-five units are produced and launched. Launch schedule based on NASA/MSFC Nominal OTV Mission Model, dated 2/29/80 (reference 1).

4. Ground Test. 1.75 equivalent hardware units were assumed for costing purposes. Ground testing includes: propulsion system and structural system testing including fatigue and vibration; Deployment Adapter Functional Test, Avionics Functional Tests, Thermal Vacuum Tests, and launch site verification. The production cost of one set of ASE was included in ground test hardware.

5. Flight Test. One proto-flight unit and one test flight were included for each development. Full price of a Shuttle launch ($25.4 million) plus operations was charged to the OTV program for each test flight. The production cost of one set of ASE was included for flight test.

6. Ground Support Equipment. Development cost plus the cost to produce three sets was included.

7. Facilities and equipment are excluded from the cost estimates.

8. OTV/Orbiter integration costs are excluded (Orbiter mods, KSC mods, overall program management and integration).

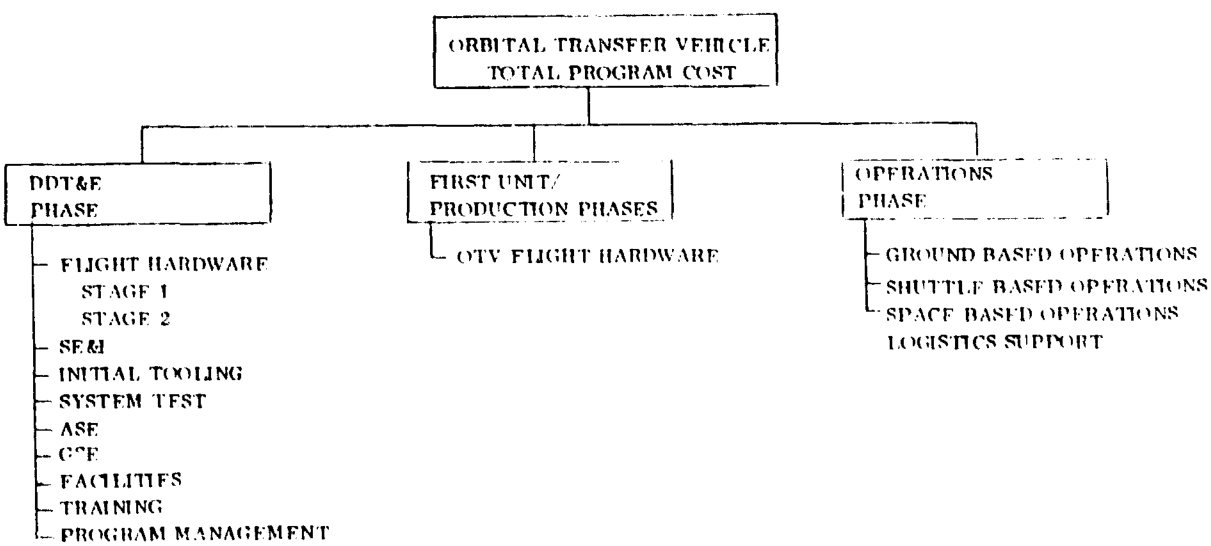


Figure 7-1. Summary work breakdown structure.

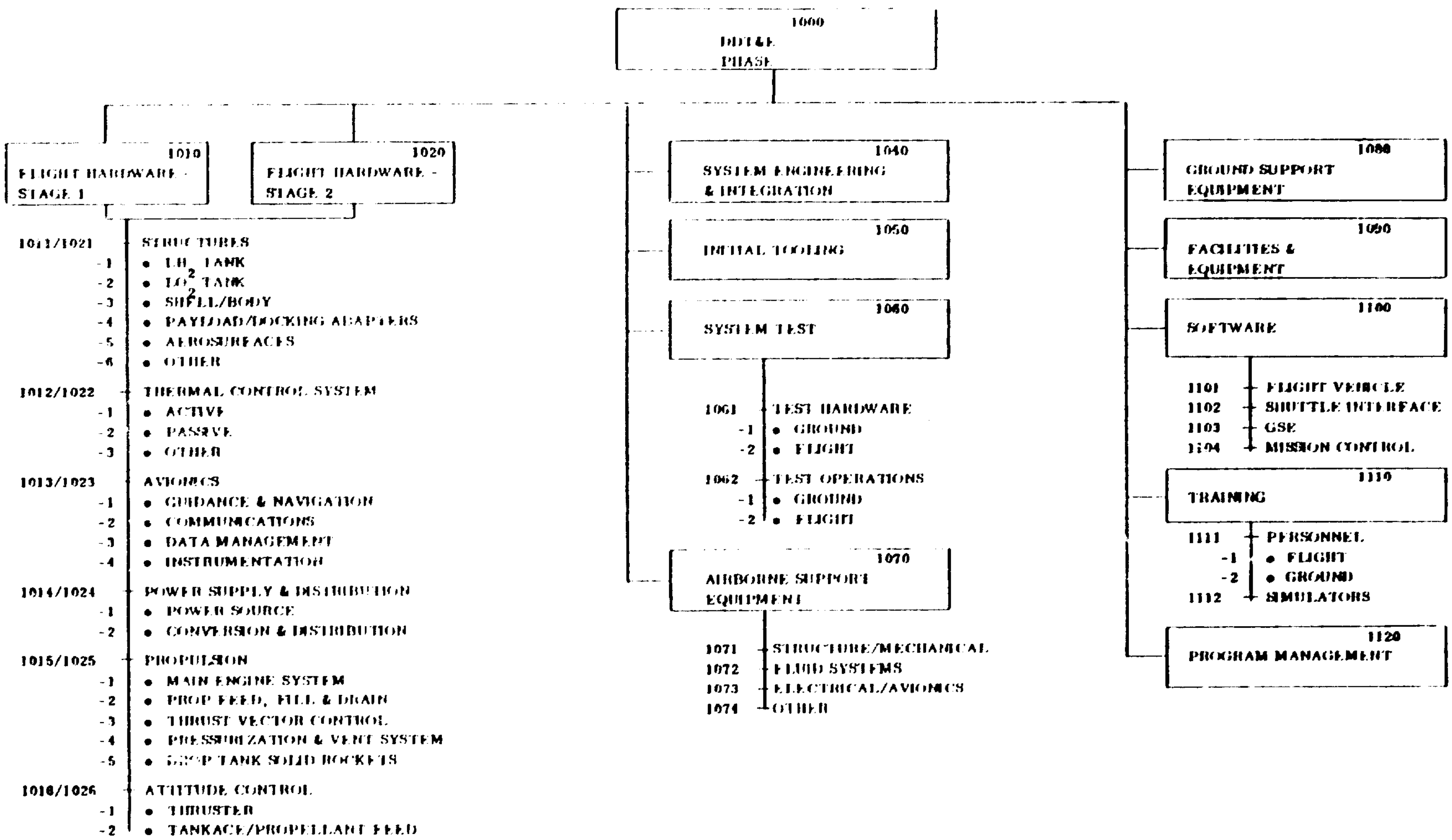


Figure 7-2. DDT&E WBS.

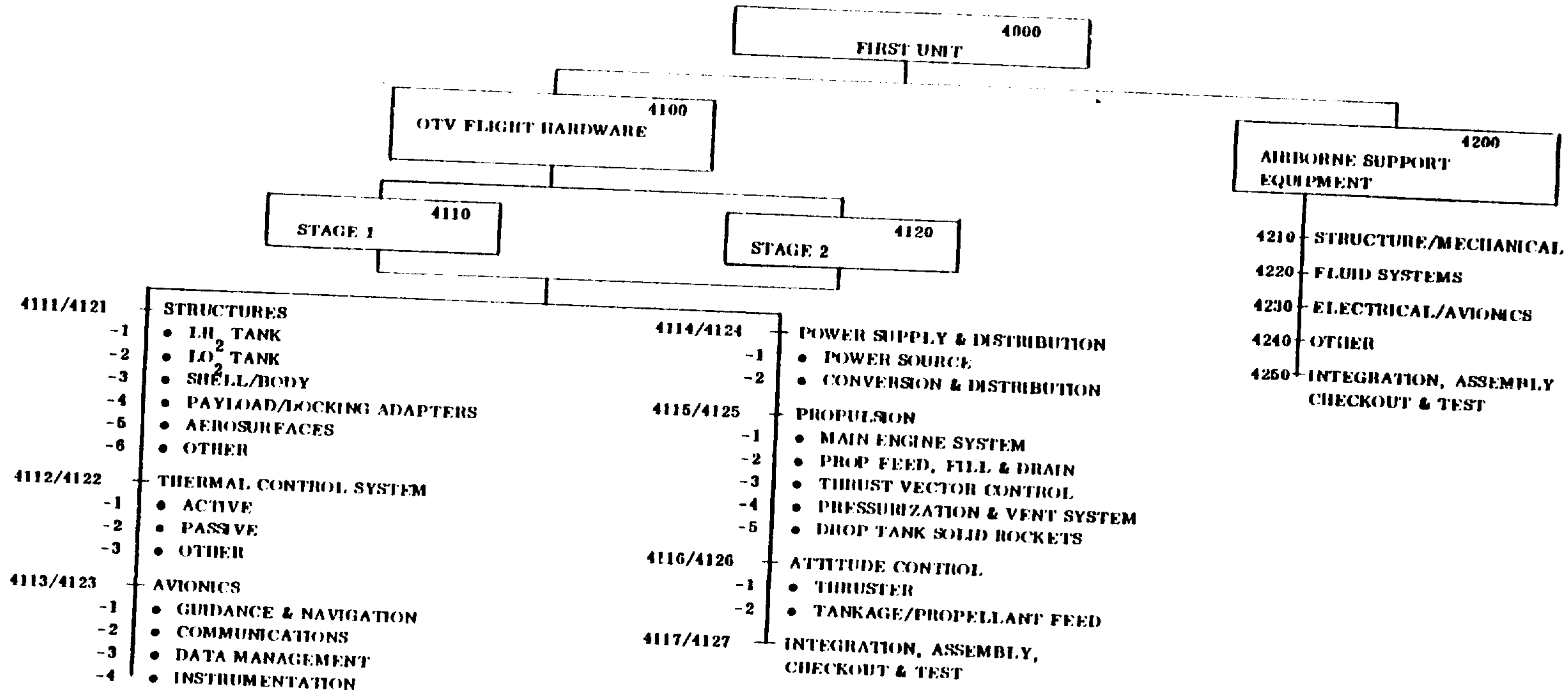


Figure 7-3. First unit WBS.

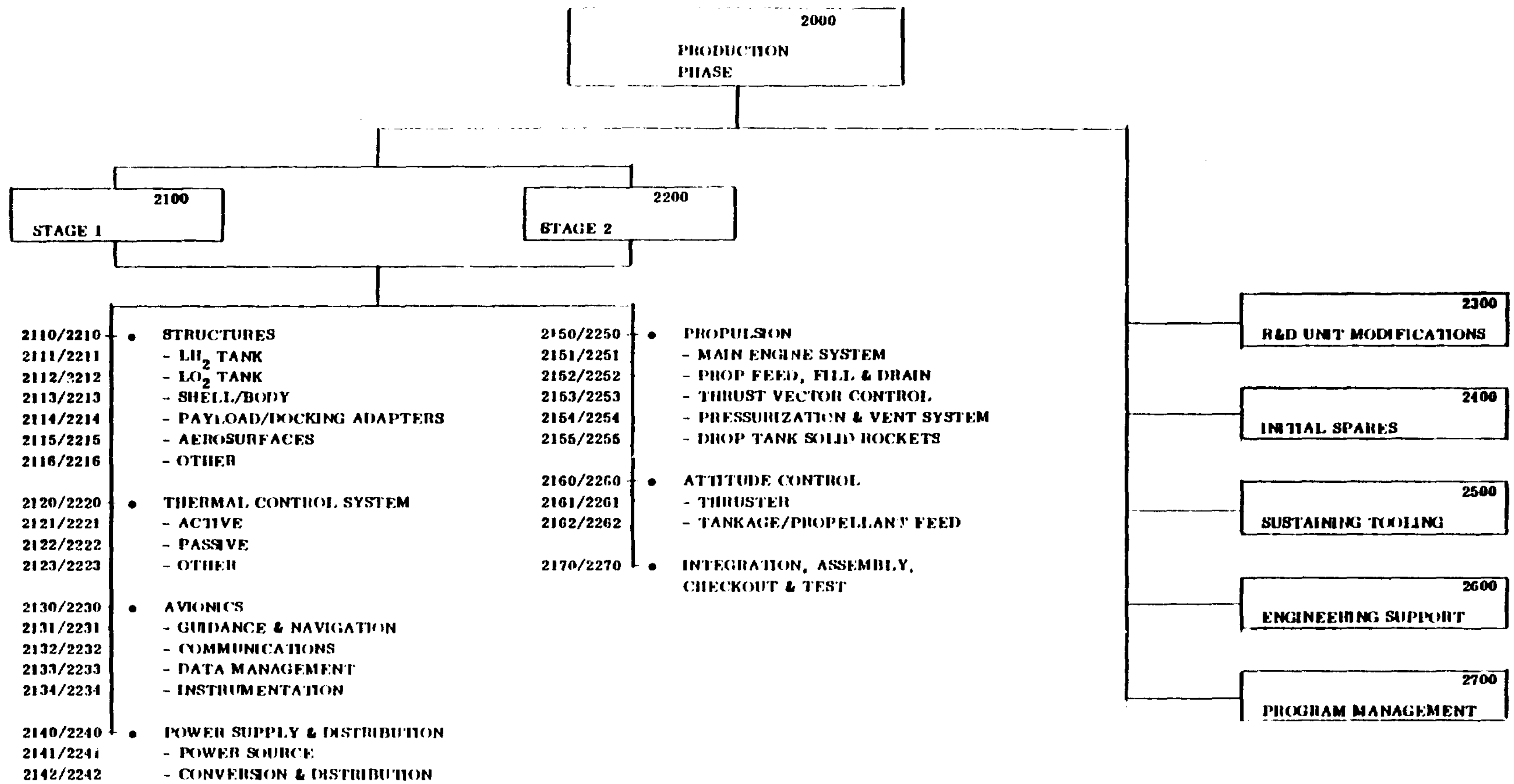


Figure 7-4. Production phase WBS.

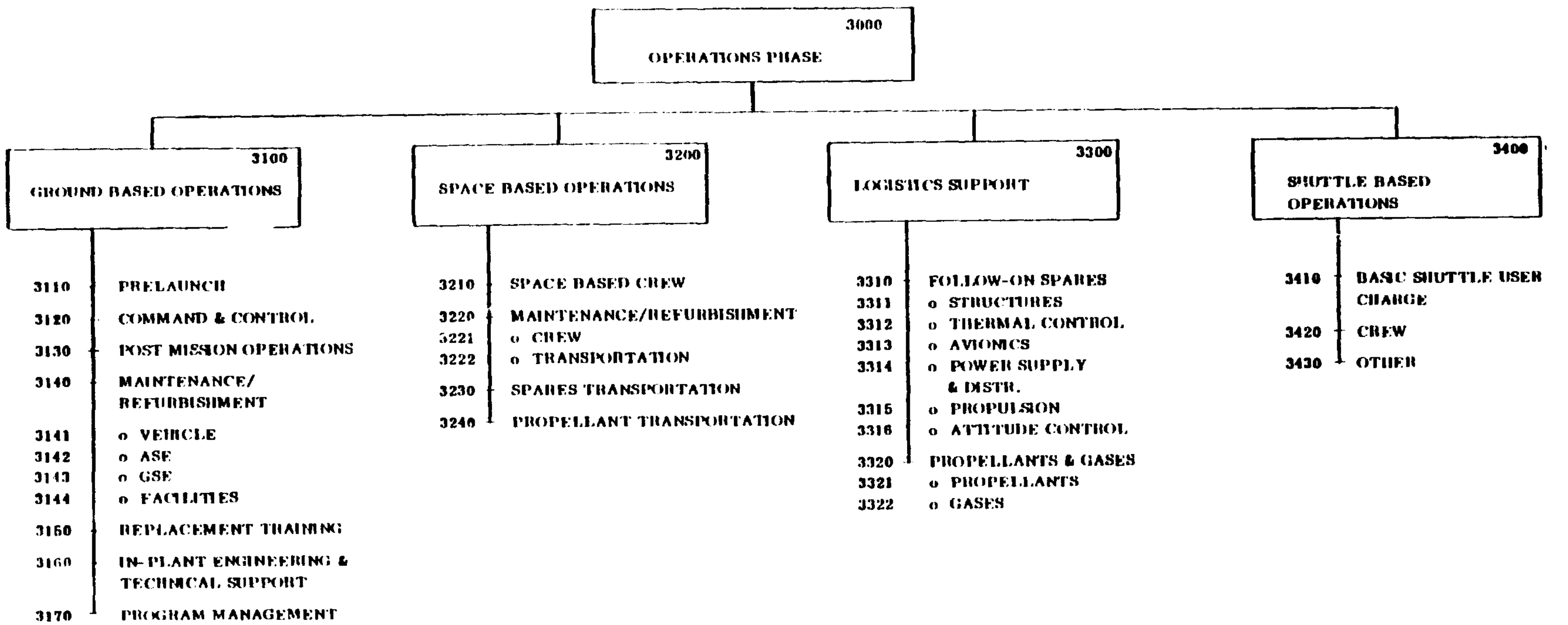


Figure 7-5. Operations phase WBS.

9. 40% of Avionics system components are off-the-shelf or already developed. Fuel cell is a modified shuttle design. All other components are new development.

10. Shuttle user charges are $25.4 million per launch. It was assumed that no additional charges would be incurred for extravehicular activity or additional on-orbit stay time.

11. Production learning rates are shown below. Production was based on 25 units at a 2 per year rate.

LEARNING CURVES FOR OTV

SUBSYSTEM	%	LC = n + 1
Structures	90	.848
Thermal Control	85	.766
Avionics	95	.926
Power Supply	95	.926
Main Engine	99	.985
Propulsion	90	.848
Solid Rockets	90	.848
Attitude Control	90	.848
I, A, C/O, Test	85	.766

12. Initial spares were based on 10% of hardware development costs.

7.3 COSTS FOR THE LOW THRUST OTV

The finalized conceptual definition of the low thrust OTV is shown in Section 5. The design is totally current state of the art. Some features, however, will require a great deal more development than others. For example, the toroidal tank concept has been proven but still will require the development of manufacturing techniques and testing to assure its performance under all required conditions. The engine will be a new design using current technology. The avionics system will be a combination of both new and off-the-shelf hardware.

Costs for the optimized low thrust OTV program are provided in Tables 7-1 and 7-2. Costs are provided down to the hardware subsystem level. Appendix 13 contains the computer printout from which Tables 7-1 and 7-2 are derived. Costs in the Appendix are presented down to WBS Level 5, or one level lower. Development costs are \$536.6 million. The largest contributors to this are the engine, avionics, and structures development. Production costs for 25 units average \$12.82 million per unit. Avionics and propulsion constitute over half of that total. Operations cost, excluding the Shuttle user charge, is \$5.13 million per launch. This cost assumes a launch rate of about 2 vehicles per year. Total program cost, for 25 units, is \$1622.22 million, or \$64.89 million per vehicle if DDT&E is amortized over 25 units.

Table 7-1. Low thrust OTV development and theoretical first unit costs.

(MILLIONS OF 1979 $)

COST ELEMENT	DDT&E		FIRST UNIT	
FLIGHT HARDWARE		292.6		13.19
STRUCTURES	54.6		1.41	
THERMAL CONTROL	16.7		1.01	
AVIONICS	53.0		4.29	
POWER SUPPLY AND DISTRIBUTION	11.1		1.49	
PROPULSION	146.2		2.63	
ATTITUDE CONTROL	11.0		1.18	
I.A, C/O, AND TEST	-		1.18	
SYSTEMS ENGINEERING AND INTEGRATION		46.6		
INITIAL TOOLING		3.3		
SYSTEM TEST		122.1		
TEST HARDWARE	44.1			
TEST OPERATIONS	78.0			
AIRBORNE SUPPORT EQUIPMENT		14.3		3.92
GROUND SUPPORT EQUIPMENT		21.2		
SOFTWARE		10.2		
TRAINING		3.6		
PROGRAM MANAGEMENT		22.7		
TOTAL		536.6		

Table 7-2. Production and operation costs.
(Millions of 1979 $)

COST ELEMENT	PRODUCTION: TOTAL FOR 25 UNITS	PRODUCTION: AVG. PRODUCTION UNIT COST	OPERATIONS: TOTAL FOR 25 UNITS	OPERATIONS: AVERAGE COST PER LAUNCH	TOTAL RECURRING
Flight Hardware	219.64	8.78			8.78
Structures	21.56	8.62			
Thermal Control	11.88	.48			
Avionics	84.57	3.38			
Power Supply and Distribution	29.42	1.18			
Propulsion	40.24	1.61			
Attitude Control	18.11	.72			
I, A, C/O & Test	13.87	.55			
Spares	21.96	.88			0.88
Sustaining Tooling	17.57	.70			0.70
Engineering Support	43.93	1.76			1.76
Program Management	17.57	.70			0.70
Ground Based Operations		.70	123.87	4.95	4.95
Prelaunch			2.00		
Command and Control			53.90		
Maintenance/Refurbishment			8.89		
Replacement Training			3.50		
In-Plant Engr's & Technical Spt			47.26		
Program Management			8.32		
Logistics Support			4.40	.18	0.18
Follow-On Spares			1.17		
Propellants/Gases			3.24		
Shuttle Based Operations			636.68	25.47	25.47
User Charge			635.00		
Crew			1.68		
TOTAL	320.67	12.82	764.95	30.60 (5.13 Without Shuttle)	43.42

NOTE: Production and Launch Costs Based on 25 Units.

7.4 PROGRAM SCHEDULE/FUNDING REQUIREMENTS

The program schedule was based on the NASA/MSFC nominal OTV mission model, reference 1. Twenty-five missions were selected which required a low thrust OTV and whose payload requirements fell within the capacity of the low thrust vehicle. Three missions were selected: the Geostationary Platform, including the demonstration article (13 units); DoD Class 2 (4 units); and Space Based Radar (8 units). The first flight is in 1987 with the launch of the Geostationary Platform Demonstration Article. The last launch is in 2000. The launches are shown in the top portion of Figure 7-6.

The program schedule is also provided in Figure 7-6. The development program occurs over a four-year time span (1983/1986). It includes hardware and software

development as well as extensive ground and flight system tests. The units are produced at a low rate, approximately 2 per year. A higher production rate would result in the requirement to store finished vehicles for several years before use. Thus, vehicles would have to be subjected to extensive checkout or refurbishment before being made operational (much like the Atlas F at Vandenberg, WTR). The low rate also keeps the production line open for future program extension or to provide spares. The 25 launches occur over a 14-year period during the operations phase. Launch rates vary from 1 to 3 per year with an average of about 2.

The schedule shown in Figure 7-6 also contains the costs for each activity. These were obtained from Tables 7-1 and 7-2. Using these costs and the timing of events, funding requirements were determined. These are shown in Figure 7-7 and are provided in detail in Table 7-3. Although the Shuttle user charges are part of the operations phase, they are provided separately due to their large contribution to cost. Shuttle charges comprise about 39% of the total program cost.

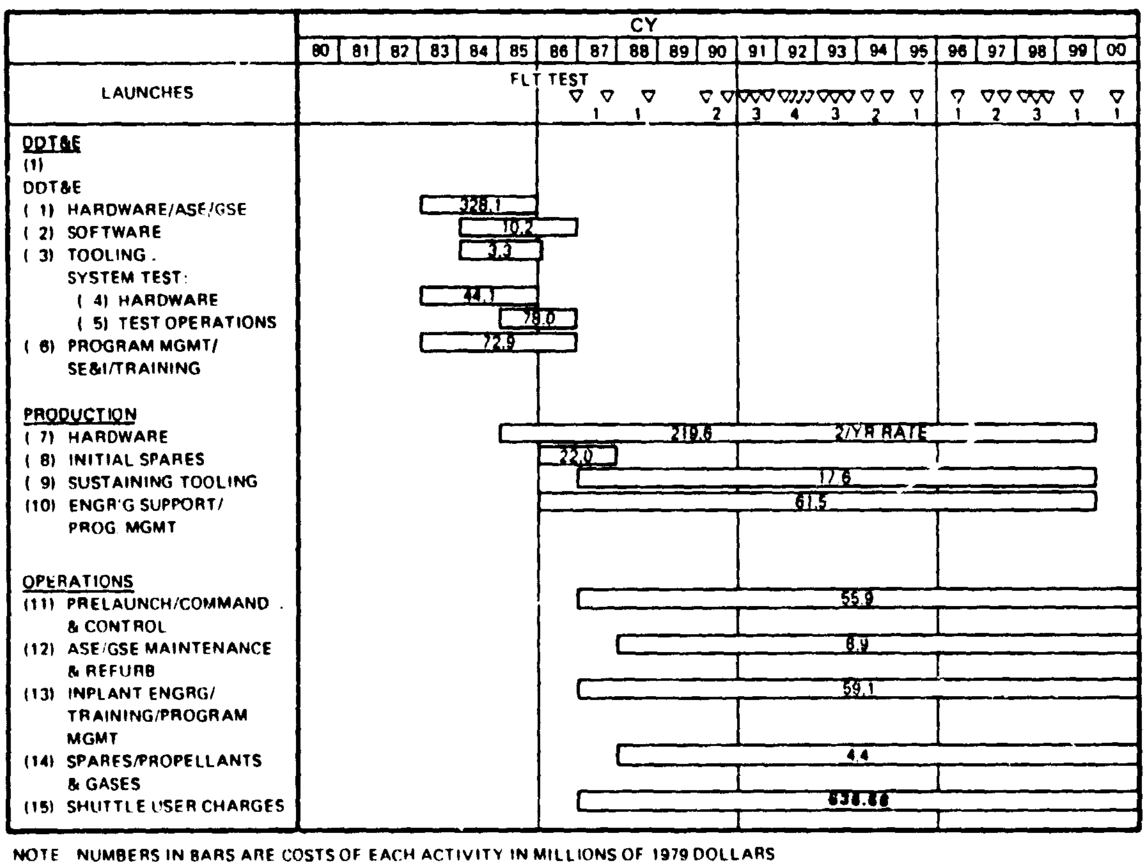


Figure 7-6. Low thrust OTV program schedule.

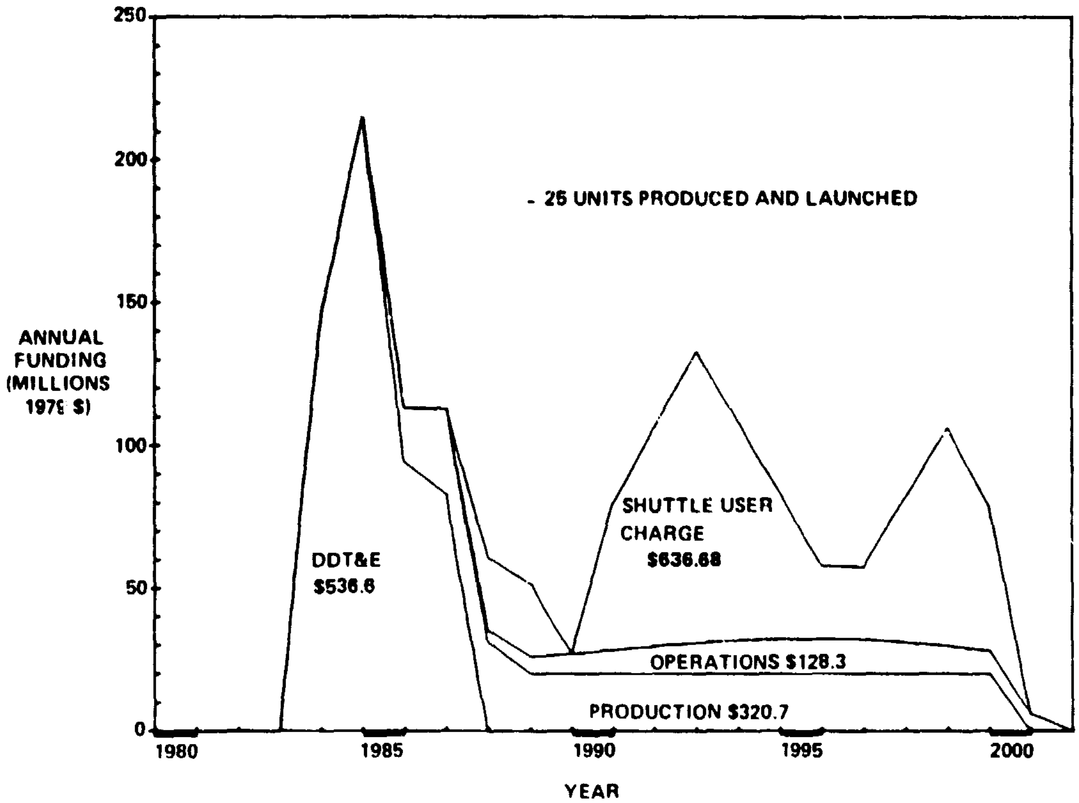


Figure 7-7. Low thrust OTV annual funding requirements.

Table 7-3. Low thrust OTV funding requirements.

YEAR	DDT&E	PRODUCTION	OPERATIONS	SHUTTLE USER CHARGE
1983	144.8			
1984	214.7			
1985	94.3	18.7		
1986	82.8	29.7		
1987		31.1	4.1	25.47
1988		20.1	5.9	25.47
1989		20.1	7.0	0
1990		20.1	8.4	50.94
1991		20.1	9.7	76.41
1992		20.1	10.9	101.88
1993		20.1	11.8	76.41
1994		20.1	12.2	50.94
1995		20.1	12.3	25.47
1996		20.1	11.8	25.47
1997		20.1	10.9	50.94
1998		20.1	9.5	76.41
1999		20.1	7.8	50.94
2000			6.0	
TOTAL	536.6	320.7	128.3	636.68

The maximum funding requirement occurs in 1984 during the development phase. Extending the length of the phase would reduce this somewhat but would slip the production phase and the 1987 and 1988 launch objectives could not be met. The high peak-year funding in 1984 is a result of the time constraints imposed by the OTV mission model. Following the development phase, the production and operations costs are relatively constant (1987 through 2000) at about $30 million per year. The Shuttle user charge, because of its high unit cost, shows a very pronounced variation with the launch rate and causes an erratic expenditure profile.

The engine costs were based on CER's (from the GDC Space Systems Life Cycle Cost Model).

It was assumed a new 1000# thrust engine would be developed (Fixed Nozzle, Conventional design).

8

REFERENCES

1. Saxton, D.R., Preliminary OTV Mission Models, Revision 2, NASA/MSFC Memorandum P504 (80-33), February 29, 1980.

2. DoD/STS On-Orbit-Assembly Concept Design Study, Final Report, Vol I, 11 Oct 1978, GDC Report CASD-AFS-77-005-39, General Dynamics Convair Division.

3. Low Thrust Chemical Orbit to Orbit Propulsion System Propellant Management Study, Monthly Progress Reports, MCR-79-657, Martin Marietta Corp.

4. OTV Engine Study, Phase A Extension Task 9 Report, Alternate Low Thrust Capability, 19 Mar 1980, Rocketdyne Division Rockwell International Corp., RI/RD 80-123.

5. Orbit Transfer Vehicle Engine Study, Task 5 Report, Low Thrust Capability FR-12898, 1 Feb 1980, Pratt & Whitney Aircraft Group.

6. Orbit Transfer Vehicle Engine Study, Parametric Data Book, FR12253, 1 Oct 1979, Pratt & Whitney.

7. On-Orbit Assembly Concept Design Study – Trajectory Design Analysis for Low Thrust Liquid Stage, by L.A. Cowgill, General Dynamics Convair Report 697-0-78-002, January 1978.

8. Performance Advantages of Constant Acceleration vs. Constant Thrust for Low Acceleration LEO to GEO Transfers, by L.A. Cowgill, General Dynamics Convair Report 697-0-79-001, January 1979.

9. Primary Propulsion LSSI Study, Monthly Progress Reports, MCR-79-653, Martin Marietta Corp.

10. Blatt, M.H., and Walter, M.D., Centaur Propellant Acquisition System Study, NAS CR-134811, CASD-NAS-75-023, NAS3-17802, June 1975.

11. Blatt, M.H., et al, Low Gravity Propellant Control Using Capillary Devices in Large Scale Cryogenic Vehicles, Phase 1 Final Report, GDC-DDB70-007, NAS8-21465, August 1970.

12. "Pressure Losses in Three-Leg Pipe Junctions: Dividing Flows", Engineering Sciences Data Item Number 73022, October 1973.

13. "Pressure Losses in Curved Ducts: Single Bends", Engineering Sciences Data Item Number 77008, May 1977.

14. Cady, E.C., Study of Thermodynamic Vent and Screen Baffle Integration for Orbital Storage and Transfer of Liquid Hydrogen, NAS CR-134482, MDC G4798, NAS3-15846, August 1973.

15. "Pressure Losses in Flow Through a Sudden Contraction of Duct Area", Engineering Sciences Data Item Number 78007, December 1977.

16. Centaur-in-Shuttle Integration Study, GDC Report No. 670-0-80-83, 28 March 1980.

17. Low Thrust Vehicle Concept Study, LSST/Low Thrust Propulsion Technology Information Exchange Meeting, 20 May 1980, by Bill Ketchum, General Dynamics. Convair Division.

18. OTV Engine Study, Phase "A" extension 1, Alternate Low-Thrust Capability, 30 April, Report 32999E1-T2, Aerojet Liquid Rocket Co.

19. Low Thrust Chemical Rocket Study, Monthly Progress Reports, ASR-80, Rocketdyne Division, Rockwell International Corp.

20. Low Thrust Chemical Rocket Engine Study, Monthly Progress Reports, 21940, Aerojet Liquid Rocket Co.

21. Low Thrust Vehicle Concept Study, First Progress Review, 30 Nov 1979, General Dynamics Convair Div.

22. Astrophysics Project Concept Summary: Gravity Wave Interferometer, Mar 78, NASA.

23. Low Thrust Vehicle Concept Study, Progress Review, 24 Jan 1980.

24. Low Thrust Vehicle Concept Study, Final Review, 15 May 1980, General Dynamics, Convair Division.

25. Low Thrust Vehicle Concept Study, Data Dump, 4 April 1980, General Dynamics Convair Division.

26. OTV Configuration Development, CASD-ERR-77-050, Dec 1977, General Dynamics, Convair Division.

27. OTV Configuration Development, CASD-ERR-78-066, Dec 1978, General Dynamics, Convair Division.

28. Orbit Transfer Vehicle, GDC-ERR-79-062, Dec 1979, General Dynamics, Convair Division.

29. AIAA Paper #79-0880. Orbit Transfer Vehicle Propulsion for Transfer of Shuttle-Deployed Large Spacecraft to Geosynchronous Orbit, W.J. Ketchum, General Dynamics Convair Division.

APPENDIX 1

DEFINITIONS OF ALGORITHMS –
SPACE BASED RADAR-A AND GEO PLATFORM ANALYSES

Computer Symbol	Analytical Symbol	Algorithms, Definition
A	a	$.5\left[2C_1 \cos 150° + (C_1{}^2 + 2\,r_s^2)^{.5}\right]$, Truss face width
AA	α	$\left[6M_f\right]^{1/3}$, Membrane edge angle causing maximum membrane stress
AC	A_c	$2\pi \ell a^2/144$, Circular area of antenna, ft^2
AL	α	$\beta_1{}^2/2$, Term in K_o
BØ	β_o	$\left[\beta^2 - \beta_1^4/4\right]^{.5}$, Term in K_o, damped resonant frequency
B1	b_1	Time at start of thrust cut-off ramp
B2	β_2	$\left[3M_f\right]^{1/3}$, Membrane edge angle affecting maximum truss bending loads
B5	b_5	$(1/\beta_o)\tan^{-1}\left[(-G_4G_2 - G_5\,k/b)/(G_1G_2 + G_3\,k/b)\right]$, Time at thrust start up at which K_o occurs
B9	b_9	$(1/\beta_o)\tan^{-1}\left\{-\left[(\beta/b)\,H_5 + \beta\,H_6/(b_2 - b_1) + (k/db)\,H_7 + k\,H_2/d\,(b_2 - b_1)\right]/\left[(\beta/b)\,H_1 + \beta\,H_2/(b_2 - b_1) + (k/db)H_3 + k\,H_4/d\,(b_2 - b_1)\right]\right\}$, Time after completion of thurst cutoff at which K_o occurs
B	b	Time at completion of thrust start up ramp
BC	b_c	$-(1/\beta_o)\tan^{-1}\left\{\left[-\beta\,J_3 - (k/d)\,J_4\right]/\left[\beta\,J_1 + (k/d)\,J_2\right]\right\}$, Adjustment in b_1 to maximize K_o at thrust cutoff
BE	β	$\left[g\,(W_z + W_w)\,k/W_wW_z\right]^{.5}$, Term in K_o, undamped resonant frequency

Definitions of Algorithms - Space Based Radar and Geo Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
BF	β_1	$\left[g(W_z + W_w)d/W_z W_w\right]^{.5}$, Term in K_o, damping parameter
BP	b^1	Thrust cutoff ramp interval
BT	b_2	$b_1 + b^1$, Time at completion of thrust cutoff ramp
C1	C_1	$3d_1 + 4d_2$, Height of one stowed truss bay
C2	C_2	$2(d_1 + k_1 d_1 + d_2)$, Length of one stowed truss bay
CD	c_d	Critical damping fraction
D1	d_1	Diameter of primary struts
D2	d_2	Diameter of diagonal struts
D	d	$c_d\left[k W_t/g\right]^{.5}$, Damping constant
DD		Increment in d_1
DM		Minimum d_1
DT	Δ	Attachment eccentricity of membrane
DX		Maximum d_1
E	E	Youngs modulus truss construction material
EE	ϵ	Eccentricity in longeron
EM	E_m	Membrane tensile modulus
F1	ϕ_1	$\tan^{-1}(2\alpha\beta_o/(\beta_o^2 - \alpha^2))$, Term in K_o, phasing angle
FA	F_a	$N_a \ell_a \sin\alpha \sin 30°$, Axial force on truss due to membrane

Definitions of Algorithms - Space Based Radar and GEO Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
FB	F_b	Joint weight factor in truss
FC	F_c	$N_d \ell_a \sin \beta_2$, End bending load on truss due to N_d
FD	F_d	$N_d \ell_a \cos 15° \cos \beta_2$, Axial load on truss due to N_d
FI	ϕ	$\tan^{-1} (\beta_o / -\alpha)$, Term in K_o, phasing angle
FS	FS	$(L_c + L_p)/L_q$, Fraction of total cargo bay length utilized
G1	G_1	$-\alpha \cos \phi + \beta_o \sin \phi + \alpha e^{\alpha b} \cos (\beta_o b + \phi)$ $- \beta_o e^{\alpha b} \sin (\beta_o b + \phi)$
G2	G_2	$d/b (1 - d \beta_1^2/4k)^{.5}$
G3	G_3	$-(\alpha/\beta_o) \cos \phi_1 + \sin \phi_1 + (\alpha/\beta_o) e^{\alpha b} \cos (\beta_o b + \phi_1)$ $- e^{\alpha b} \sin (\beta_o b + \phi_1)$
G4	G_4	$\alpha \sin \phi + \beta_o \cos \phi - \alpha e^{\alpha b} \sin (\beta_o b + \phi)$ $- \beta_o e^{\alpha b} \cos (\beta_o b + \phi)$
G5	G_5	$(\alpha/\beta_o) \sin \phi_1 + \cos \phi_1 - (\alpha/\beta_o) e^{\alpha b} \sin(\beta_o b + \phi_1)$ $- e^{\alpha b} \cos (\beta_o b + \phi_1)$, Factors in b_5
G	g	Gravity acceleration
H1	H_1	$-\alpha \cos \phi + \beta_o \sin \phi + \alpha e^{\alpha b} \cos (\beta_o b + \phi)$ $- \beta_o e^{\alpha b} \sin (\beta_o b + \phi)$
H2	H_2	$-\alpha e^{\alpha b_2} \cos (\beta_o b_2 + \phi) + \beta_o e^{\alpha b_2} \sin (\beta_o b_2 + \phi)$ $+ \alpha e^{\alpha b_1} \cos (\beta_o b_1 + \phi) - \beta_o e^{\alpha b_1} \sin (\beta_o b_1 + \phi)$

Definitions of Algorithms - Space Based Radar and GEC Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
H3	H_3	$-\alpha\cos\phi_1 + \beta_0\sin\phi_1 + \alpha e^{\alpha b}\cos(\beta_0 b + \phi_1)$
		$-\beta_0 e^{\alpha b}\sin(\beta_0 b + \phi_1)$
H4	H_4	$-\alpha e^{\alpha b_2}\cos(\beta_0 b_2 + \phi_1) + \beta_0 e^{\alpha b_2}\sin(\beta_0 b_2 + \phi_1)$
		$+\alpha e^{\alpha b_1}\cos(\beta_0 b_1 + \phi_1) - \beta_0 e^{\alpha b_1}\sin(\beta_0 b_1 + \phi_1)$
H5	H_5	$\alpha\sin\phi + \beta_0\cos\phi - \alpha e^{\alpha b}\sin(\beta_0 b + \phi)$
		$-\beta_0 e^{\alpha b}\cos(\beta_0 b + \phi)$
H6	H_6	$\alpha e^{\alpha b_2}\sin(\beta_0 b_2 + \phi) + \beta_0 e^{\alpha b_2}\cos(\beta_0 b_2 + \phi)$
		$-\alpha^{\alpha b_1}\sin(\beta_0 b_1 + \phi) - \beta_0 e^{\alpha b_1}\cos(\beta_0 b_1 + \phi)$
H7	H_7	$\alpha\sin\phi_1 + \beta_0\cos\phi_1 - \alpha e^{\alpha b}\sin(\beta_0 b + \phi_1)$
		$-\beta_0 e^{\alpha b}\cos(\beta_0 b + \phi_1)$
H8	H_8	$\alpha e^{\alpha b_2}\sin(\beta_0 b_2 + \phi_1) + \beta_0 e^{\alpha b_2}\cos(\beta_0 b_2 + \phi_1)$
		$-\alpha e^{\alpha b_1}\sin(\beta_0 b_1 + \phi_1) - \beta_0 e^{\alpha b_1}\cos(\beta_0 b_1 + \phi_1)$,
		Factors in b_9
H	h	$2a\cos 30°$, Height of truss
I1	I_1	$\pi d_1^3 t_1/8$, Longeron moment of inertia
IS	I_{sp}	$458 - 5.49\times 10^{-10}(2500 - T_t)^{3.20}$, Specific impulse
J1	J_1	$\alpha e^{\alpha b^1}\cos(\beta_0(t - b_1 - b^1) - \phi)$
		$+\beta_0 e^{\alpha b^1}\sin(\beta_0(t - b_1 - b^1) - \phi)$
		$-\alpha\cos(\beta_0(t - b_1) - \phi)$
		$-\beta_0\sin(\beta_0(t - b_1) - \phi)$

Definitions of Algorithms - Space Based Radar and GEO Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
J2	J_2	$\alpha e^{\alpha b^1} \cos(\beta_0 (t - b_1 - b^1) - \phi_1)$ $+ \beta_0 e^{\alpha b^1} \sin(\beta_0 (t - b_1 - b^1) - \phi_1)$ $- \alpha \cos(\beta_0 (t - b_1) - \phi_1)$ $- \beta_0 \sin(\beta_0 (t - b_1) - \phi_1)$
J3	J_3	$\alpha e^{\alpha b^1} \sin(\beta_0 (t - b_1 - b^1) - \phi)$ $- \beta_0 e^{\alpha b1} \cos(\beta_0 (t - b^1) - \phi)$ $- \alpha \sin(\beta_0 (t - b_1) - \phi)$ $+ \beta_0 \cos(\beta_0 (t - b_1) - \phi)$
J4	J_4	$\alpha e^{\alpha b1} \sin(\beta_0 (t - b_1 - b^1) - \phi_1)$ $- \beta_0 e^{\alpha b^1} \cos(\beta_0 (t - b_1 - b^1) - \phi_1)$ $- \alpha \sin(\beta_0 (t - b_1) - \phi_1)$ $+ \beta_0 \cos(\beta_0 (t - b_1) - \phi_1)$, Factors in b_c
KØ	K_o	K_2, if $K_3 > K_2$ then $K_o = K_3$, Maximum thrust start-up or cutoff amplification factor
K1	k_1	Packaging factor for truss in C_2
K2	K_2	$(1/k) \left\{ (d/b) \left[e^{-\alpha t} \sin(\beta_0 t - \phi) - e^{-\alpha (t-b)} \sin(\beta_0 (t-b) - \phi) \right] / (1 - d \beta_1^2/4k)^{1/2} + (k/b) \left[b + (1/\beta_0) \left(e^{-\alpha t} \sin(\beta_0 t - \phi_1) - e^{-\alpha (t-b)} \sin(\beta_0 (t-b) - \phi_1) \right) \right] \right\}$ Thurst startup amplification factor

Definitions of Algorithms - Space Based Radar and GEO Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
K3	K_3	$(d/k)\Big\{(\beta/b\,\beta_o)\Big[e^{-\alpha t}\sin(\beta_o t-\phi)-e^{-\alpha(t-b)}\sin(\beta_o(t-b)-\phi)\Big]$ $+\Big[\beta/(b_2-b_1)\,\beta_o\Big]\Big[e^{-\alpha(t-b_2)}\sin(\beta_o(t-b_2)-\phi)$ $-e^{-\alpha(t-b_1)}\sin(\beta_o(t-b_1)-\phi)\Big]$ $+(k/d)\Big\{(1/b)\Big[b+(1/\beta_o)\Big(e^{-\alpha t}\sin(\beta_o t-\phi_1)$ $-e^{-\alpha(t-b)}\sin(\beta_o(t-b)-\phi_1)\Big)\Big]$ $+\Big[1/(b_2-b_1)\Big]\Big[-b_2+b_1+(1/\beta_o)\Big(e^{-\alpha(t-b_2)}\sin(\beta_o(t-b_2)-\phi_1)$ $-e^{-\alpha(t-b_1)}\sin(\beta_o(t-b_1)-\phi_1)\Big)\Big]\Big\}\Big\}$, Thrust cutoff amplification factor - after completed cutoff
K4		Programmed part of K3
K5	K_5	Dummy variable for K_o, maximum value of K_o at thrust startup.
K6	K_6	Dummy variable for K_o, maximum value of K_o at thrust cutoff
K7	K_7	Maximum amplification factor at thrust cutoff due to thrust startup transient
K8	K_8	$(d/k)\Big\{(\beta/b\,\beta_o)\Big[e^{-\alpha t}\sin(\beta_o t-\phi)-e^{-\alpha(t-b)}\sin(\beta_o(t-b)-\phi)\Big]$ $+\Big[\beta/(b_2-b_1)\,\beta_o\Big]\Big[-e^{-\alpha(t-b_2)}\sin(\beta_o(t-b_1)-\phi)-\beta_o/\beta\Big]$ $+(k/d)\Big\{(1/b)\Big[b+(1/\beta_o)\Big(e^{-\alpha t}\sin(\beta_o t-\phi_1)$ $-e^{-\alpha(t-b)}\sin(\beta_c(t-b)-\phi_1)\Big)\Big]$ $+\Big[1/(b_2-b_1)\Big]\Big[-t+b_1+2\alpha/\beta^2$

Definitions of Algorithms - Space Based Radar and GEO Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
K8	K_8	(continued) $-(1/\beta_0)\, 4^{-\alpha(t-b_1)}\ \sin(\beta_0(t-b_1) - \phi_1]\ \}\}$ Thrust cutoff amplification factor - after start of thrust cutoff
K	k	$1.5\,\pi h^2 d_1 t_1 E/\ell_a^{\,3}$, Nominal truss cantilever spring rate
KP	k_p	Propellant weight loss per hour for power up to first 12 hours
KQ	k_q	Propellant weight loss per hour for power after first 12 hours
KS	k_s	Propellant weight loss per engine start
KT	k_t	Propellant weight loss per hour due to leakage, boiloff and attitude control
KU,KV	K_u, K_v	Factors in WA, $K_u = 3$, $K_v = 5$ for SBR-A and $K_u = 4$, $K_v = 9$ for SBR-R and GEO platform
LA	ℓ_a	Truss length - deployed
LB	L_b	$L_q - L_p$, Available cargo bay length for structure and its add-ons
LC	L_c	$L_b \ell_a/\ell_x$, Length of stowed truss structure
LD		Increment in LA
LM		Minimum LA
LP	L_p	$(12 + .75 \times 10^{-4} P_w)12$, OTV stage length
LQ	L_q	Available cargo bay length for total shuttle payload and OTV

Definitions of Algorithms - Space Based Radar and GEO Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
LX	ℓ_x	aL_b/C_2, Maximum LA due to Shuttle length fit
LZ		Dummy variable for LA
M1	M_1	$\left\| F_c \ell_a + W_t \ell_a T_w K_o + (1/2) W_a \ell_a^2 T_w K_o + F_b (\Delta + h) \right\|$, Truss bending moment - membrane separating from truss
M2	M_2	$\left\| W_t \ell_a T_w K_o + (1/2) W_a \ell_a^2 T_w K_o - F_a \Delta + .289 W_1 \ell_a^3 T_w K_o \right\|$, Truss bending moment - membrane acting on truss
MF	M_f	$W_1 T_w K_o \ell_a / t_e E_m 2$, Membrane factor
MH	M_h	Fraction of membrane occupied by holes
MU	u	Mass fraction
MZ	M_z	$.85 + 5 \times 10^{-7} P_w$, Mass fraction - dummy variable
N	N	Number of burns
NA	N_a	$W_1 K_o T_w \ell_a /2 \sin \alpha$, Membrane edge load intensity - drooped
ND	N_d	$W_1 T_w K_o \ell_a/2 \sin \beta_2$, Membrane edge load intensity - non-drooped
P	p	$\frac{M_1}{h}$ or $\frac{M_2}{h}$ = PJ whichever is larger
PJ		Axial load on longeron alternate P
PC	P_{cr}	$\pi^2 E I_1/a^2$ or
	P_{cr}	$\sigma_1 \pi d_1 t_1/(1 + \epsilon d_1/2 r_1^2)$ = PK, whichever is smaller

Definitions of Algorithms - Space Based Radar and GEO Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
PK		Critical longeron buckling load alternate P_{cr}
PL	P_ℓ	$k_s N + k_t t_q + P_p$, total payload losses
PP	P_p	$k_p t_q$ for $t_q \leq 12$ hrs., $k_p 12 + k_q (t_q - 12)$ for $t_q > 12$ hrs. Propellant weight loss for onboard power generation
PW	P_w	W_x u, Propellant weight
R_1	r_1	$.354 d_1$, Longeron radius of gyration
RH	ρ	Structural material density
RM	ρ_m	Membrane material density
RS	r_s	Usable shuttle cargo bay radius
S1	σ_1	Yield stress of truss construction material
SM	σ_m	N_a/t_e, Membrane stress
SP	σ'_m	Allowable membrane stress
TØ		minimum TA
T1	t_1	Wall thickness of primary struts
T2	t_2	Wall thickness of diagonal struts
T3, T4	T'_{w3}, T'_{w4}	Initial thrust-to-weight ranges in V_1, V_2
T	t	Time
TA	t_a	Full membrane thickness
TD		Increment in T1

Definitions of Algorithms - Space Based Radar and GEO Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
TE	t_e	$t_a \lfloor (.907/M_h)^{.5} - 1 \rfloor$, Effective membrane thickness i.e., that reacts loads
TF		Increment in TW
TG		Increment in TA
TM		Minimum T1
TN		Minimum TW
TP	T'_w	$T_w \left[W_w + (1 - u)(W_s - W_w) \right] / W_s$ Thrust to weight ratio of OTV - initial (for constant thrust engine performance)
TQ	t_q	$t_r + t_s$, Mission time
TR	t_r	25 for N = 9 10 for N = 5 5 for N = 2 Coast time, hours
TS	t_s	$P_w I_{sp}/T_t$ 3600, Burn time, hours
TT	T_t	$T_p W_s$, OTV engine thrust
TX		Maximum T1
TW	T_w	Thrust to weight ratio of OTV - final
TY		Maximum TW
TZ		Maximum TA

Definitions of Algorithms - Space Based Radar and GEO Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
V1, V2	V_1, V_2	

If $T_w' > .001$ and $T_w' < .01$ and $N = 9$ then $V_1 = 17300$, $V_2 = 14500$, $T'_{w_3} = .001$, $T'_{w_4} = .01$

.001	.01	5	17800	15700	.001	.01
.001	.01	2	18400	17100	.001	.01
.01	.1	9	14500	14000	.01	.1
.01	.1	5	15700	14100	.01	.1
.01	.1	2	17100	14400	.01	.1
.1	1.0	9	14000	13500	.1	1.0
.1	1.0	5	14100	13500	.1	1.0
.1	1.0	2	14400	13500	.1	1.0

Factors in V, velocity ranges for constant thrust curves.

Computer Symbol	Analytical Symbol	Algorithms, Definition
V	V	$V_1 - \left[(V_1 - V_2)/(T'_{w_4} - T'_{w_3})\right]\left[T'_w - T'_3\right]$, Velocity requirements for LEO-GEO transfer
W1	W_1	$t_e \rho_m + W_L$, Membrane plus array unit area weight
WA	W_a	$F_b \rho \left[K_u \pi d_1 t_1 (.857) + K_v \pi d_2 t_2 (.794)\right]$, Weight per unit length of truss
WB	W_b	$W_a \ell_a$, Weight of one truss in SBR-A or entire ring in SBR-R
WC	W_c	$W_1 \, 3 \, \ell_a \cos 30°$, Weight of lens. (In GEO platform this is a part of the hub weight)
WH	W_h	$.46 (W_w - W_h)$, Weight of hub
WL	w_L	Unit area weight of lens array
WS	W_s	Stage total weight
WT	W_t	Weight on end of truss
WW	W_w	$6 W_b + W_c + 6 W_t + W_h$, Total payload weight for SBR-A

Definitions of Algorithms - Space Based Radar and GEO Platform Analyses (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
WX	W_x	$W_s - W_y$, Loaded stage weight
WY	W_y	$(W_s/u)\left[\exp(-V/I_{sp}g)\right] + u - 1 \quad -P_{\ell}$, OTV payload capability - single Shuttle
WY	W_y	$W_s\left\{u \exp(V/I_{sp}g)/\left[\exp(V/I_{sp}g) - 1\right] - 1\right\} - P_{\ell}$, OTV payload capability - double shuttle
WZ	W_z	$(1 - u)(W_s - W_w)$, Weight of orbital transfer stage - empty
ZH		Hub weight fraction

APPENDIX 2

DEFINITIONS OF ALGORITHMS – SPACE BASER RADAR-R ANALYSIS

(New Terms and * Redefinitions of terms in Table 1)

Computer Symbol	Analytical Symbol	Algorithms, Definition
A1	A_1	$\pi d_1 t_1$, Area of longitudinal member
AM	α	$I/A_1 \ell_a^2$, Hoop stress deformation factor
AT	A_t	$3 A_1$, Total truss cross-section area
BU	β	$EI/GA_t \ell_a^2$, Transverse shear deformation factor
DA	d_a	$157.38 - 9.23d_1$, Storage envelope for lens - outside diameter and inside diameter for packaged ring truss
DB	d_b	Inside diameter of stowed lens package
*FS	FS	$(a + L_F + L_P)/L_q$, Fraction of cargo bay occupied by payload and OTV
GE	G	Shear modulus
I	I	$2A_1 \bar{x}^2 + (a \cos 30° - \bar{x})^2 A_1$, Moment of inertia of ring truss
KA	k_1	$1 + \alpha + \beta$
KB	k_2	$1 - \alpha + \beta$
KC	k_3	k_2/k_1, Hoop stress correction factors
*LA	ℓ_a	Lens radius
LF	L_F	Length of feed structure
* LM		Minimum LA

Definitions of Algorithms - Annular Phased Array Analysis (cont'd)

Computer Symbol	Analytical Symbol	Algorithms, Definition
*LX	ℓ_x	$\left[(d_a^2 - d_b^2)\ 2a/3t_L\right]^{.5} / 2$, Maximum LA
*M1	M_1	$W \ell_a^2 \left[-1/4 + (1/\pi)(1 - k_4/3 + 3\ \pi/8)\right]$, Maximum moment in ring truss
NO	N_o	$2\pi \ell_a/a$, Number of structural truss bays in ring circumference
*P	P	$M_1/(a \cos 30° - \bar{x})$, Axial load on longeron
TL	t_L	Thickness of lens
W	W	$2\pi \ell_a\ W_1 T_w K_o$, Peak loading intensity or ring truss due to lens
*WA	W_a	$F_b\ \rho \left[3\pi d_1 t_1 (.857) + 5\pi d_2 t_2 (.794)\right] + W_a^1$, Weight per unit length of truss
WB	W_b	$W_a\ 2\pi\ \ell_a$, Weight of ring truss structure
*WC	W_c	$W_1\ \pi \ell_a^2$, Weight of lens
WN	W_n	Weight per node
WP	W_a^1	$3\ W_n/a$, Distributed weight of nodes per unit length of truss
*WW	W_w	$W_c + W_b + W_h$, Total payload weight
XB	$\bar{x}$	$(a/3) \cos 30°$, Neutral axis location from face of truss structure.

APPENDIX 3. OPTOTV COMPUTER SYMBOLS DEFINITIONS

SBR-A, SBR-R AND GEO PLATFORM ANALYSES

SYMOTV/OOA - SYMBOLS USED IN OPTOTV/OOA

A1 - AREA OF LONGITUDINAL MEMBER
A - TRUSS FACE WIDTH, LONGERON LENGTH
AA - MEMBRANE EDGE ANGLE CAUSING MAXIMUM MEMBRANE STRESS
AC - CIRCULAR AREA OF ANTENNA IN SQUARE FEET
AL - TERM IN K0
AM - HOOP STRESS DEFORMATION FACTOR
AT - TOTAL TRUSS CROSS SECTION AREA
B0 - TERM IN K0, DAMPED RESONANT FREQUENCY
B1 - TIME AT START OF THRUST CUT OFF RAMP
B1% - NEAREST INTEGER NUMBER OF CYCLES BEYOND THRUST START UP PEAK FOR B1
B2 - MEMBRANE EDGE ANGLE AFFECTING MAXIMUM TRUSS BENDING LOADS
B4 - DUMMY VARIABLE FOR B1
B5 - TIME OF THRUST START UP PEAK K0
B6 - TIME BEYOND START OF THRUST CUT OFF AT PEAK K0
B9 - TIME AFTER COMPLETION OF THRUST CUT OFF AT WHICH PEAK K0 OCCURS
B - TIME AT COMPLETION OF THRUST START UP RAMP
BC - ADJUSTMENT IN B1 TO MAXIMIZE K0 AT THRUST CUT OFF
BE, BF - TERMS IN K0
BP - THRUST CUT OFF RAMP INTERVAL
BT - TIME AT COMPLETION OF THRUST CUT OFF RAMP
BU - TRANSVERSE SHEAR DEFORMATION FACTOR
C1 - HEIGHT OF STOWED TRUSS BAY
C2 - LENGTH OF STOWED TRUSS BAY
CD - CRITICAL DAMPING FRACTION
D1 - DIAMETER OF PRIMARY STRUTS
D1% - DUMMY VARIABLE FOR INCREMENTING D1
D2 - DIAMETER OF DIAGONAL STRUTS
D - DAMPING CONSTANT
DA - STORAGE ENVELOPE FOR LENS - OUTSIDE DIAMETER AND INSIDE DIAMETER FOR PACKAGED RING TRUSS
DB - INSIDE DIAMETER OF STOWED LENS PACKAGE
DC - DUMMY VARIABLE FOR DM
D0 - INCREMENT IN D1
D0% - INCREMENT IN D1%
DM - MINIMUM D1
DM% - MINIMUM D1%
DT - ATTACHMENT ECCENTRICITY OF MEMBRANE
DV - INCREMENT IN MU
DX - MAXIMUM D1
DX% - MAXIMUM D1%
DY - DUMMY VARIABLE FOR DX
E - YOUNG'S MODULUS TRUSS CONSTRUCT MATERIAL
EE - ECCENTRICITY IN LONGERON
EM - MEMBRANE TENSILE MODULUS
F1 - TERM IN K0
FA - AXIAL FORCE ON TRUSS DUE TO MEMBRANE
FB - JOINT WEIGHT FACTOR IN TRUSS
FC - END BENDING LOAD ON TRUSS DUE TO ND
FD - AXIAL LOAD ON TRUSS DUE TO ND
FI - TERM IN K0
FS - FRACTION OF CARGO BAY OCCUPIED BY PAYLOAD AND OTV
G1-G5 - FACTORS IN B5
G - GRAVITATION CONSTANT

GE - SHEAR MODULUS
H - HEIGHT OF TRUSS
H1-H8 - FACTORS IN B9
I - MOMENT OF INERTIA OF RING TRUSS
I1 - LONGERON MOMENT OF INERTIA
IS - SPECIFIC IMPULSE
J1-J4 - FACTORS IN BC
K0 - THRUST CUT OFF AMPLIFICATION FACTOR, LARGEST OF K2 OR K5
K1 - PACKAGING FACTOR FOR TRUSS
K2 - THRUST START UP AMPLIFICATION FACTOR
K3 - THRUST CUT OFF AMPLIFICATION FACTOR AFTER COMPLETED CUT OFF
K4 - FACTOR IN K3
K5 - DUMMY VARIABLE FOR K0, MAXIMUM VALUE OF K0 AT THRUST CUT OFF
K6 - DUMMY VARIABLE FOR K0, MINIMUM VALUE OF K0 AT THRUST CUT OFF
K7 - MAXIMUM AMPLFICATION FACTOR AT THRUST CUT OFF DUE TO THRUST START UP TRANSIENT
K8 - THRUST CUT OFF AMPLIFICATION FACTOR AFTER START OF CUT OFF
K9 - THRUST START UP AMPLIFICATION FACTOR - FIRST MAXIMUM AFTER B
K - NOMINAL TRUSS CANTILEVER SPRING RATE
KA,KB,KC - HOOP STRESS CORRECTION FACTORS
KE - MAXIMUM K8
KP - PROPELLANT WEIGHT LOSS PER HOUR FOR POWER UP TO FIRST 12 HOURS
KQ - PROPELLANT WEIGHT LOSS PER HOUR FOR POWER AFTER FIRST 12 HOURS
KS - PROPELLANT WIEGHT LOSS PER ENGINE START
KT - PROPELLANT WEIGHT LOSS PER HOUR DUE TO LEAKAGE, BOIL OFF AND ALTITUDE CONTROL
KU,KV - CONSTANTS IN HA FOR DIAMOND AND TRIANGULAR BOOM CROSS SECTIONS
KX,KY,KZ - DUMMY VARIABLES IN COMPUTING K5,K6 & K7
LA - TRUSS LENGTH OR LENS RADIUS
LB - AVAILABLE CARGO BAY LENGTH FOR STOWED TRUSS STRUCTURE AND ITS ADD-ONS
LC - LENGTH OF STOWED TRUSS STRUCTURE
LD - TRUSS LENGTH INCREMENT - DEPLOYED
LF - LENGTH OF FEED STRUCTURE
LL - DUMMY VARIABLE FOR LZ
LM - MINIMUM TRUSS LENGTH - DEPLOYED
LP - LENGTH OF OTV
LQ - CARGO BAY LENGTH AVAILABLE FOR TOTAL SHUTTLE PAYLOAD
LU - DUMMY VARIABLE FOR LX
LX - MAXIMUM LA
LY - DUMMY VARIABLE FOR LM
LZ - DUMMY VARIABLE FOR LA ALSO REINITIALIZED MINIMUM LA
M1 - TRUSS BENDING MOMENT (SBR) OR MAXIMUM MOMENT IN RING TRUSS (APA)
M2 - TRUSS BENDING MOMENT - MEMBRANE ACTING ON TRUSS
MF - MEMBRANE FACTOR
MH - FRACTION OF MEMBRANE OCCUPIED BY HOLES
MU - MASS FRACTION
MV - MINIMUM MU
MZ - DUMMY VARIABLE FOR MU
N - NUMBER OF BURNS
NA - MEMBRANE EDGE LOAD INTENSITY - DROOPED
ND - MEMBRANE EDGE LOAD INTENSITY - UNDROOPED
NO - NUMBER OF STRUCTURAL TRUSS BAYS IN RING CIRCUMFERENCE
P - AXIAL LOAD ON LONGERON
PC - CRITICAL LONGERON BUCKLING LOAD

PI - 3.1416
PJ - ALTERNATE P
PK - ALTERNATE PC
PL - TOTAL PAYLOAD LOSSES
PP - PROPELLANT WEIGHT LOSS FOR POWER
PW - PROPELLANT WEIGHT
Q6% - DUMMY VARIABLE FOR D1(N)
R1 - LONGERON RADIUS OF GYRATION
RH - STRUCTURAL MATERIAL DENSITY
RM - MEMBRANE MATERIAL DENSITY
RS - USABLE SHUTTLE CARGO BAY RADIUS
S1 - YIELD STRESS OF TRUSS CONSTRUCTION MATERIAL
SM - MEMBRANE STRESS
SP - ALLOWABLE MEMBRANE STRESS
T0 - MINIMUM TA
T1 - WALL THICKNESS OF PRIMARY STRUTS
T1% - DUMMY VARIABLE FOR INCREMENTING T1
T2 - WALL THICKNESS OF DIAGONAL STRUTS
T3,T4 - INITIAL THRUST-TO-WEIGHT RANGES IN V1 AND V2 RESPECTIVELY
T - TIME, IN DYNAMICS ANALYSIS AND IN SBR PRINT OUT, TIME AFTER START OF THRUST CUT OFF AT WHICH K8 IS MAXIMUM
TA - FULL MEMBRANE THICKNESS
TB - DUMMY VARIABLE FOR TN
TC - DUMMY VARIABLE FOR TM
TD - INCREMENT IN T1
TD% - INCREMENT IN T1%
TE - EFFECTIVE MEMBRANE THICKNESS (I.E. THAT REACTS LOADS)
TF - INCREMENT IN TW
TF% - INCREMENT IN TW%
TG - INCREMENT IN TA
TL - LENS THICKNESS
TM - MINIMUM T1
TM% - MINIMUM T1%
TN - MINIMUM TW
TN% - MINIMUM TW%
TP - THRUST TO WEIGHT RATIO OF OTV-INITIAL
TQ - MISSION TIME IN HOURS
TR - COAST TIME, HOURS
TS - BURN TIME, HOURS
TT - OTV ENGINE THRUST
TU - DUMMY VARIABLE FOR TX
TW - THRUST TO WEIGHT RATIO OF OTV-FINAL
TW% - DUMMY VARIABLE FOR INCREMENTING TW
TX - MAXIMUM T1
TX% - MAXIMUM T1%
TY - MAXIMUM TW
TY% - MAXIMUM TW
TZ - MAXIMUM TA
V1,V2 - FACTORS IN V, VELOCITY RANGES
V - VELOCITY REQUIREMENTS FOR LEO-GEO TRANSFER
W1 - MEMBRANE PLUS ARRAY UNIT AREA WEIGHT
W - PEAK LOADING INTENSITY ON RING TRUSS DUE TO LENS
WA - WEIGHT PER UNIT LENGTH OF TRUSS
WB - WEIGHT OF ONE TRUSS IN SBR OR ENTIRE RING IN APA
WC - WEIGHT OF LENS

WH - WEIGHT OF HUB
WL - ARRAY UNIT AREA WEIGHT
WN - WEIGHT PER NODE
WP - DISTRIBUTED WEIGHT OF NODES PER UNIT LENGTH OF TRUSS
WS - TOTAL PAYLOAD PLUS LOADED STAGE WEIGHT
WT - WEIGHT ON END OF ONE TRUSS
WU - INITIAL INPUT PAYLOAD WEIGHT FOR GEO PLATFORM PAYLOAD
WV - DUMMY VARIABLE FOR WU
WW - TOTAL PAYLOAD WEIGHT
WX - LOADED STAGE WEIGHT
WY - OTV PAYLOAD CAPABILITY
WZ - WEIGHT OF ORBITAL TRANSFER STAGE - EMPTY
XB - NEUTRAL AXIS LOCATION FROM FACE OF TRUSS STRUCTURE IN APA
ZH - HUB WEIGHT FRACTION OF WC, WT AND REFLECTOR STRUCTURE WEIGHT
ZI - AVERAGE BOOM WEIGHTS IN GEO PLATFORM ANALYSIS
ZO - SBR N=2 OPTION IDENTIFIER
ZU - DESIGNATION FOR APA, GEO PLATFORM OR SPACE BASED RADAR ANALYSIS
ZW - DUMMY VARIABLE FOR ALTERNATIVE APA PRINT OUTS
ZX, ZY - PRINT CONTROL VARIABLES
ZZ - INPUT VARIABLE FOR TYPE OF PAYLOAD DESIRED
ZZ$ - PRINT CONTROL VARIABLE ASSOCIATED WITH ZZ

APPENDIX 4. OPTOTV PROGRAM LISTING (BASIC)

```
10 CLEAR 290: 'OPTOTV/OOA
20 PRINT "ENTER 0 IF PAYLOAD IS TO BE IN OTV AND SHUTTLE": PRINT "ENTER 1 IF PAYLOAD IS TO BE IN SHUTTLE ONLY": PRINT "ENTER 2 IF TW
O SHUTTLE FLIGHTS ARE TO BE CONSIDERED": INPUT"ZZ";ZZ
30 PRINT "(1) GEO PLATFORM ANALYSIS": PRINT "(2) ANNULAR ARRAY": PRINT "(3) SPACE BASED RADAR ANALYSIS": INPUT "ZU";ZU
35 PRINT"(1) SBR CONSTANT TW,N=2 ANALYSIS":INPUT "ZO";ZO
40 READ RS,EM,T2,D2,K1,WT,EE,E,FB,DM,DD,TN,TY,TF,TM,TD,SP,S1,DT,RH,MH,T0,TZ,TG,RM,B,B1,PI,LM,LD,G,HL,WS,CD,BP,MV,DV,LQ,KS,KT,KP,KQ,W
U,ZH,DB,GE,WN,TL,LF
50 DATA 88,.3E+06,.025,1.0,.2,1  ,.107,40.0E+06,3.218,2,.1,.01,.41,.04,.05,.005,3330,37000,3,.063,.6,.002,.02,.009,.0513,1,100,3.14
1592654,1000,10,32.17,3.3E-04,60000,.014,1,.85,.01,684,15.4 1,21,.5,10502,.47,36,.354E+07,10,.125,40
60 ZZ$(1)="1 PAYLOAD, 1 OTV, 1 SHUTTLE": ZZ$(2)="1 PAYLOAD, 1 SHUTTLE": ZZ$(3)="1 PAYLOAD, 1 OTV, 2 SHUTTLES"
70 LPRINT"OPTOTV/OOA - ";ZZ$(ZZ+1):IF ZU=1 THEN LPRINT "GEO PLATFORM ANALYSIS",CHR$(10),CHR$(10):GOTO 80 ELSE IF ZU=2 THEN LPRINT "A
NNULAR PHASED ARRAY",CHR$(10),CHR$(10): GOTO 80: ELSE IF ZU=3 THEN LPRINT "SPACED BASED RADAR ANALYSIS",CHR$(10),CHR$(10)
75 IF ZO=1 THEN LPRINT "SBR CONSTANT TW, N=2 ANALYSIS",CHR$(10),CHR$(10)
80 LPRINT "B1","B","BP","CD","D2","DB","DD","DM","DT","DV","E","EE","EM","FB","G","GE","K1","KP","KQ","KS","KT","LD","LF","LM","LQ"
,"MH","MV","PI","RH","RM","RS","S1","SP","T2",
90 LPRINT "T0","TD","TF","TG","TL","TM","TN","TY","TZ","WL","WN","WS","WT","WU","ZH",CHR$(10),CHR$(10)
100 IF ZU=1 THEN LQ=372: LM=107.2: WT=844: DM=1: DD=.1: TD=.005: TM=.01: ZH=.46: WU=10502:TY=2:LD=0: ELSE IF ZU=2 THEN FB=1
110 LPRINT B1,B,BP,CD,D2,DB,DD,DM,DT,DV,E,EE,EM,FB,G,GE,K1,KP,KQ,KS,KT,LD,LF,LM,LQ,MH,MV,PI,RH,RM,RS,S1,SP,T2,T0,TD,TF,TG,TL,TM,TN,T
Y,TZ,WL,WN,WS,WT,WU,ZH,CHR$(10),CHR$(10): LPRINT STRING$(120,45): LPRINT STRING$(120,45)
120 LPRINT STRING$(2,138): PRINT "OPTOTV/OOA IS RUNNING": LY=LM:TB=TN:TC=TM:DC=DM:TU=TX:DY=DX
130 FOR N=9 TO 2 STEP -3
135 IF ZO=1 THEN N=2
140 TN=TB:TM=TC:DM=DC:TX=TU:DX=DY:ZX=0:ZY=0:WV=WU
150 LZ=LM: TX=TM+TD: DX=DM+DD
160 IF N=6 THEN N=5
170 TX%=(TX*1000+.5): TM%=(TM*1000+.5): TD%=(TD*1000+.5)
180 FOR T1%=TM% TO TX% STEP TD%
190 T1=T1%/1000
200 DX%=(DX*100+.5): DM%=(DM*100+.5): DD%=(DD*100+.5)
210 FOR D1%=DM% TO DX% STEP DD%
220 D1=D1%/100
230 TY%=TY*100+.5: TN%=TN*100+.5: TF%=TF*100+.5
240 FOR TW%=TN% TO TY% STEP TF%
250 TW=TW%/100
260 C1=3*D1+4*D2: C2=2*(D1+K1*D1+D2): A=.5*(2*C1*(-.866)+(C1[2+2*RS[2)[.5): LX=1E+06: IF LZ<0 THEN LZ=20
270 IF ZU=2 THEN A=300
280 IF ZU=1 THEN LX=LZ
290 FOR LA= LZ TO LX STEP LD
300 AC=2*PI*LA[2/144
310 FOR TA=T0 TO TZ STEP TG
320 IF ZU=1 OR ZU=2 THEN KU=3: KV=5: ELSE KU=4: KV=9
330 WP=3*WN/A: WA=FB*RH*(KU*PI*D1*T1*.857+KV*PI*D2*T2*.794): TE=TA*((.987/MH)[.5-1): W1=TE*RM+WL: IF ZU=1 THEN ZI=6*WA*LM ELSE IF ZU
=2 THEN WA=WA+WP
340 FOR MU=MV TO 1 STEP DV
350 IF ZU=1 THEN 360 ELSE 370
360 WW=WV: WZ=(1-MU)*(WS-WW): WX=WS-WW: PW=MU*WX: MZ=.85+5*10[-7*PW: IF MZ>MU THEN 400 ELSE 410
370 IF ZU=2 THEN 380 ELSE 390
380 WC=PI*W1*LA[2: WB=WA*2*PI*LA: WH=ZH*(WC+WB): WW=WC+WB+WH: WZ=(1-MU)*(WS-WW): WX=WS-WW: PW=MU*WX: MZ=.85+5*10[-7*PW: IF MZ>MU THE
N 400 ELSE 410
390 WB=WA*LA: WC=W1*3*LA[2*.866: WW=6*WB+WC+6*WT: WH=ZH*WW: WW=WW+WH: WZ=(1-MU)*(WS-WW): WX=WS-WW: PW=MU*WX: MZ=.85+5*10[-7*PW: IF
MZ>MU THEN 400 ELSE 410
400 NEXT MU
410 LP=12*(12+.75*10[-4*PW): IF ZZ=1 OR ZZ=2 THEN LP=0
420 IF ZU=2 THEN LB=LQ-LP-LF: DA=157.38-9.23*D1: LX=((DA[2-DB[2)*2*A/(3*TL))[.5/2: LU=LX: FS=(A+LF+LP)/LQ: IF A>LB THEN 1910 ELSE 44
0
```

```
430 LB=LQ-LP: LU=A*LB/C2: LX=LU: LC=LB*LA/LX: FS=(LC+LP)/LQ: IF ZU=1 THEN LC=0
440 ON ERROR GOTO 1650
450 H=2* A66*A: K=1.5*PI*H[2*D1*T1*E/(LA[3): BE=(387*(HH+HZ)*K/(HH*HZ))[.5: D=CD*(K*HT/G)[.5: BF=(387*(HH+HZ)*D/(HH*HZ))[.5
460 B0=(BE[2-BF[4/4)[.5: AL=BF[2/2: FI=ATN(B0/(-AL)): F1=ATN(2*AL*B0/(B0[2-AL[2))
470 GOTO 870
480 G1=-AL*COS(FI)+B0*SIN(FI)+AL*EXP(AL*B)*COS(B0*B+FI)-B0*EXP(AL*B)*SIN(B0*B+FI): G2=D/(B*(1-D*BF[2/(4*K))[.5): G3=-(AL/B0)*COS(F1)
+SIN(F1)+(AL/B0)*EXP(AL*B)*COS(B0*B+F1)-EXP(AL*B)*SIN(B0*B+F1)
490 G4=AL*SIN(FI)+B0*COS(FI)-AL*EXP(AL*B)*SIN(B0*B+FI)-B0*EXP(AL*B)*COS(B0*B+FI): G5=(AL/B0)*SIN(F1)+COS(F1)-(AL/B0)*EXP(AL*B)*SIN(B
0*B+F1)-EXP(AL*B)*COS(B0*B+F1)
500 B5=(1/B0)*ATN((-G4*G2-G5*K/B)/(G1*G2+G3*K/B)): T=B5: IF B5<0 THEN T=B5+PI/B0
510 KZ=KZ+1
520 K2=(1/K)*((D/B)*(EXP(-AL*T)*SIN(B0*T-FI)-EXP(-AL*(T-B))*SIN(B0*(T-B)-FI))/(1-D*BF[2/(4*K))[.5+(K/B)*(B+(1/B0)*(EXP(-AL*T)*SIN(B0
*T-F1)-EXP(-AL*(T-B))*SIN(B0*(T-B)-F1))))
530 IF K2<1 THEN 540 ELSE 560
540 T=B5+PI/B0: IF T>10*PI/B0 THEN 1890
550 GOTO 520
560 IF KZ=1 THEN 570 ELSE 580
570 K9=K2: B1%=B0*B1/(2*PI): T=T+B1%*2*PI/B0: GOTO 510
580 K7=K2: KZ=0: B4=B1
590 BT=B4+BP: KY=KY+1
600 H1=(-AL*COS(FI)+B0*SIN(FI)+AL*EXP(AL*B)*COS(B0*B+FI)-B0*EXP(AL*B)*SIN(B0*B+FI))*EXP(-AL*B1): H2=-AL*EXP(AL*BP)*COS(B0*BT+FI)+B0*
EXP(AL*BP)*SIN(B0*BT+FI)-AL*COS(B0*B1+FI)-B0*SIN(B0*B1+FI)
610 H3=(-AL*COS(F1)+B0*SIN(F1)+AL*EXP(AL*B)*COS(B0*B+F1)-B0*EXP(AL*B)*SIN(B0*B+F1))*EXP(-AL*B1): H4=-AL*EXP(AL*BP)*COS(B0*BT+F1)+B0*
EXP(AL*BP)*SIN(B0*BT+F1)+AL*COS(B0*B1+F1)-B0*SIN(B0*B1+F1)
620 H5=(AL*SIN(FI)+B0*COS(FI)-AL*EXP(AL*B)*SIN(B0*B+FI)-B0*EXP(AL*B)*COS(B0*B+FI))*EXP(-AL*B1): H6=AL*EXP(AL*BP)*SIN(B0*BT+FI)+B0*EX
P(AL*BP)*COS(B0*BT+FI)-AL*SIN(B0*B1+FI)-B0*COS(B0*B1+FI)
630 H7=(AL*SIN(F1)+B0*COS(F1)-AL*EXP(AL*B)*SIN(B0*B+F1)-B0*EXP(AL*B)*COS(B0*B+F1))*EXP(-AL*B1): H8=AL*EXP(AL*BP)*SIN(B0*BT+F1)+B0*EX
P(AL*BP)*COS(B0*BT+F1)-AL*SIN(B0*B1+F1)-B0*COS(B0*B1+F1)
640 B9=(1/B0)*ATN(-(BE/B*H5+(BE/(BT-B1))*H6+(K/(D*B))*H7+(K/(D*(BT-B1)))*H2)/(BE/B*H1+BE*H2/(BT-B1)+(K/(D*B))*H3+(K/(D*(BT-B1)))*H4)
): T=B9+BT
650 IF KY=1 THEN 660 ELSE 710
660 J1=AL*EXP(AL*BP)*COS(B0*(T-B1-BP)-FI)+B0*EXP(AL*BP)*SIN(B0*(T-B1-BP)-FI)-AL*COS(B0*(T-B1)-FI)-B0*SIN(B0*(T-B1)-FI)
670 J2=AL*EXP(AL*BP)*COS(B0*(T-B1-BP)-F1)+B0*EXP(AL*BP)*SIN(B0*(T-B1-BP)-F1)-AL*COS(B0*(T-B1)-F1)-B0*SIN(B0*(T-B1)-F1)
J3=AL*EXP(AL*BP)*SIN(B0*(T-B1-BP)-FI)+B0*EXP(AL*BP)*COS(B0*(T-B1-BP)-FI)-AL*SIN(B0*(T-B1)-FI)-B0*COS(B0*(T-B1)-FI)
690 J4=AL*EXP(AL*BP)*SIN(B0*(T-B1-BP)-F1)+B0*EXP(AL*BP)*COS(B0*(T-B1-BP)-F1)-AL*SIN(B0*(T-B1)-F1)-B0*COS(B0*(T-B1)-F1)
700 BC=-(1/B0)*ATN((-BE*J3-K*J4/D)/(BE*J1+K*J2/D)): B4=B1+BC: GOTO 590
710 KY=0: KX=KX+1
720 K4=(1/(BT-B4))*(-BT+B4+(1/B0)*(EXP(-AL*(T-BT))*SIN(B0*(T-BT)-F1)-EXP(-AL*(T-B4))*SIN(B0*(T-B4)-F1))): B6=B9-B1
730 K3=(D/K)*((BE/(B*B0))*(EXP(-AL*T)*SIN(B0*T-FI)-EXP(-AL*(T-B))*SIN(B0*(T-B)-FI))+(BE/((BT-B4)*B0))*(EXP(-AL*(T-BT))*SIN(B0*(T-BT)
-FI)-EXP(-AL*(T-B4))*SIN(B0*(T-B4)-FI))+(K/D)*((1/B)*(B+(1/B0)*(EXP(-AL*T)*SIN(B0*T-F1)-EXP(-AL*(T-B))*SIN(B0*(T-B)-F1)))+K4))
740 IF K3<1 THEN 750 ELSE 760
750 T=T+PI/B0: IF T>BT+10*PI/B0 THEN 1? ? ELSE 720
760 IF KX=1 THEN 770 ELSE 780
770 T=T+PI/B0: K5=K3: GOTO 710
780 K6=K3: KX=0
790 IF K5>K2 THEN K0=K5 ELSE K0=K2
800 B1=B1%*2*PI/B0+B5
810 FOR T=B1 TO B1+BP STEP BP/18
820 K8=(D/K)*((BE/(B*B0))*(EXP(-AL*T)*SIN(B0*T-FI)-EXP(-AL*(T-B))*SIN(B0*(T-B)-FI))+(BE/((BT-B1)*B0))*(-EXP(-AL*(T-BT))*SIN(B0*(T-B1
)-FI)-B0/BE)+(K/D)*((1/B)*(B+(1/B0)*(EXP(-AL*T)*SIN(B0*T-F1)-EXP(-AL*(T-B))*SIN(B0*(T-B)-F1)))))
830 K8=K8+(1/(BT-B1))*(-T+B1+2*AL/(BE[2)-(1/B0)*EXP(-AL*(T-B1))*SIN(B0*(T-B1)-F1))
840 IF K8>KE THEN KE=K8
850 NEXT T
860 IF KE>K0 THEN K0=KE
```

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870 K0=2: IF ZU=2 THEN 880 ELSE 900
880 W=2*PI*LA*W1*TH*K0: SM=W/TE
890 XB=A* 866/3: A1=PI*D1*T1: I=2*A1*XB[2+(A* 866-XB)[2*A1: AM=I/(A1*LA[2): AT=3*A1: BU=E*I/(GE*AT*LA[2): KA=1+AM+BU: KB=1-AM+BU: KC
=KB/KA: M1=W*LA[2*(- 25+(1-KC/3+3*PI/8)/PI): NO=2*PI*LA/A: P=M1/(A* 866-XB): GOTO 960
900 MF=W1*TH*K0*LA/(2*TE*EM)
910 B2=(3*MF)[(1/3): AA=(6*MF)[(1/3): NA=W1*K0*TH*LA/(2*SIN(AA)): SM=NA/TE: IF SM>SP THEN 920 ELSE 930
920 NEXT TA
930 ND=W1*TH*K0*LA/(2*SIN(B2)): FD=ND*LA* 9659*COS(B2): FC=ND*LA*SIN(B2): FA=NA*LA*SIN(AA)* 5: M1=FC*LA+WT*LA*TH*K0+ 5*WA*LA[2*TH*K0
+FD*(DT+H): M2=WT*LA*TH*K0+ 5*WA*LA[2*TH*K0-FA*DT+ 289*W1*LA[3*TH*K0
940 P=M1/H: PJ=M2/H: IF PJ>P THEN P=PJ
950 IF ZU=1 THEN P=2*P
960 I1=PI*D1[3*T1/8: P1= 354*D1: PC=PI[2*E*I1/A[2: PK=S1*PI*D1*T1/(1+EE*D1/(2*R1[2))
970 IF PK<PC THEN PC=PK
980 IF P<PC THEN 1040 ELSE 990
990 IF ZZ=0 THEN 1000 ELSE 1010
1000 IF WY>=WW THEN 1530 ELSE 1500
1010 IF ZZ=1 THEN 1020 ELSE 1030
1020 IF WS>=WW THEN 1530 ELSE 1500
1030 IF WS>=WW AND WY>=WW AND WS>=WX THEN 1530 ELSE 1500
1040 IF ZZ=1 THEN 1360
1050 TP=TH*(WW+(1-MU)*(WS-WW))/WS: IF ZO=1 THEN TP=TH
1051 IF TP< 001 THEN 1510
1052 IF ZO=1 THEN 1261
1060 IF TP>= 001 AND TP<= 0029 AND N=9 THEN 1070  ELSE 1080
1070 V1=17300: V2=15700: T3= 001: T4= 0029: GOTO 1270
1080 IF TP>= 001 AND TP<= 0029 AND N=5 THEN 1090  ELSE 1100
1090 V1=17900:V2=16700:T3= 001:T4= 0029:GOTO 1270
1100 IF TP>= 001 AND TP<= 0029 AND N=2 THEN 1110  ELSE 1120
1110 V1=18400:V2=17700:T3= 001:T4= 0029:GOTO 1270
1120 IF TP>= 0029 AND TP<= 01 AND N=9 THEN T3= 0029: T4= 01: V1=15300: V2=14500: GOTO 1270
1130 IF TP>= 0029 AND TP<= 01 AND N=5 THEN T3= 0029: T4= 01: V1=16700: V2=15700: GOTO 1270
1140 IF TP>= 0029 AND TP<= 01 AND N=2 THEN T3= 0029: T4= 01: V1=17700: V2=17100: GOTO 1270
1150 IF TP>= 01 AND TP<= 1 AND N=9 THEN 1160  ELSE 1170
1160 V1=14500:V2=14000:T3= 01:T4= 1:GOTO 1270
1170 IF TP>= 01 AND TP<= 1 AND N=5 THEN 1180  ELSE 1190
1180 V1=15700:V2=14100:T3= 01:T4= 1:GOTO 1270
1190 IF TP>= 01 AND TP<= 1 AND N=2 THEN 1200 ELSE 1210
1200 V1=17100:V2=14400:T3= 01:T4= 1: GOTO 1270
1210 IF TP>= 1 AND TP<=1 AND N=9 THEN 1220 ELSE 1230
1220 V1=14000:V2=13500:T3= 1:T4=1:GOTO 1270
1230 IF TP>= 1 AND TP<=1 AND N=5 THEN 1240 ELSE 1250
1240 V1=14100:V2=13500: T3= 1:T4=1:GOTO 1270
1250 IF TP>= 1 AND TP<=1 AND N=2 THEN 1260 ELSE 1270
1260 V1=14400:V2=13500:T3= 1:T4=1:GOTO 1270
1261 IF TP>= 001 AND TP<= 003 THEN V1=19000: V2=18900: T3= 001: T4= 003: GOTO 1270
1262 IF TP>= 003 AND TP<= 01 THEN V1=18900: V2=18500: T3= 003: T4= 01: GOTO 1270
1263 IF TP>= 01 AND TP<= 1 THEN V1=18500: V2=14600: T3= 01: T4= 1: GOTO 1270
1264 IF TP>= 1 AND TP<=1 THEN V1=14600: V2=13500: T3= 1: T4=1
1270 V=V1-((V1-V2)/(T4-T3))*(TP-T3): TT=TP*WS: IF TT>=2500 THEN TT=2499
1275 IF ZO=1 THEN TT=40000*TP:IF TT>=2500 THEN TT=2499
1280 IS=459-5 49*(1E-10)*(2500-TT)[3 2: TT=TP*WS
1285 IF ZO=1 THEN TT=40000*TP
1290 TS=PW*IS/(TT*3600): IF N=9 THEN TP=25 ELSE IF N=5 THEN TP=10 ELSE IF N=2 THEN TP=5
1295 IF ZO=1 THEN TS=V/(TP*115920)
```

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1300 TQ=TR+TS: IF TQ<=12 THEN PP=KP*TQ ELSE PP=12*KP+KQ*(TQ-12)
1310 PL=KS*N+KT*TQ+PP
1320 IF ZZ=2 THEN WY=WS*(MU*EXP(V/(IS*G))/(EXP(V/(IS*G))-1)-1)-PL: WX=WS-WY: GOTO 1380
1330 WY=(WS/MU)*(EXP(-V/(IS*G))+MU-1)-PL: WX=WS-WY: IF ZU=1 THEN 1340 ELSE 1350
1340 IF .98*WY>WW THEN WY=WW*1.01:GOTO 340
1350 IF WY>=WW AND P<PC THEN 1370 ELSE 1480
1360 IF WS>=WW AND P<PC THEN 1370 ELSE 1480
1370 LZ=LA: IF (LA+LD)<LX THEN 1390 ELSE 1480
1380 IF WS>=WW AND WY>=WW AND WS>=WX AND P<PC THEN 1370 ELSE 1480
1390 A(N)=A: AA(N)=AA: AC(N)=AC: AL(N)=AL: B0(N)=B0: B2(N)=B2: B4(N)=B4: B5(N)=B5: B6(N)=B6: B9(N)=B9: BC(N)=BC: BE(N)=BE: BF(N)=BF:
 C1(N)=C1: C2(N)=C2: D1(N)=D1: D(N)=D: DX(N)=DX: F1(N)=F1: FA(N)=FA: FC(N)=FC: FD(N)=FD: FI(N)=FI: FS(N)=FS: ZI(N)=ZI
1400 H(N)=H: I1(N)=I1: IS(N)=IS: K0(N)=K0: K2(N)=K2: K5(N)=K5: K6(N)=K6: K7(N)=K7: K9(N)=K9: K(N)=K: KE(N)=KE: LA(N)=LA: LB(N)=LB: L
C(N)=LC: LP(N)=LP: LX(N)=LX: M1(N)=M1: M2(N)=M2: MF(N)=MF: MU(N)=MU: N(N)=N: NA(N)=NA: ND(N)=ND: P(N)=P: PC(N)=PC: PI(N)=PI
1410 PK(N)=PK: PW(N)=PW: P1(N)=R1: SM(N)=SM: T1(N)=T1: TA(N)=TA: TE(N)=TE: TP(N)=TP: TT(N)=TT: TW(N)=TW: TX(N)=TX: V(N)=V: W1(N)=W1:
 WA(N)=WA: WB(N)=WB: WC(N)=WC: WH(N)=WH: WX(N)=WX: WW(N)=WW: WY(N)=WY: WZ(N)=WZ: PL(N)=PL: TQ(N)=TQ: TR(N)=TR: TS(N)=TS
1420 W(N)=W: AM(N)=AM: BU(N)=BU: A1(N)=A1: AT(N)=AT: XB(N)=XB: I(N)=I: DA(N)=DA: NO(N)=NO: WP(N)=WP
1430 IF LL=LZ AND TW=TB THEN 1670
1440 IF LL=LZ THEN 1450 ELSE 1470
1450 IF WY<1.05*WW OR D1<=DC THEN 1710
1460 DM=D1-DD: TM=T1+TD: TX=T1+2*TD: GOTO 170
1470 NEXT LA
1480 LZ=LA : IF TW=TB AND N=N(N) AND LA>LA(N) AND D1=D1(N) AND T1=T1(N) AND TW=TW(N) GOTO 1670
1490 IF TW=TW(N) AND N=N(N) AND LA>LA(N) AND T1=T1(N) AND D1=D1(N) THEN GOTO 1710
1500 LZ=LA-LD: LL=LZ: GOTO 290
1510 NEXT TW%
1520 IF LX-LA>LD THEN 1620
1530 LL=LU: LZ=LA: TN=TW: IF LX-LA<LD THEN 1600
1540 IF DD=0 THEN 1590
1550 Q6%=D1(N)*100+.5: IF DX%=Q6% THEN 1560 ELSE 1570
1560 DM=DX+DD: DX=DX+2*DD: GOTO 200
1570 IF D1%=DX% AND T1%=TM% AND D1(N)=0 THEN 1560
1580 NEXT D1%
1590 IF TD=0 THEN 1620
1600 TM=T1+TD: TX=T1+2*TD:DM=D1:DX=D1+DD:TN=TW:GOTO 170
1610 NEXT T1%
1620 IF ZZ=1 THEN 1640
1630 GOTO 1760
1640 PRINT "PROGRAM FINISHED. ENTER CONT FOR PRINT OUT": STOP
1650 RESUME 1660
1660 ZX=1: IF TW=TB THEN 1670 ELSE 1510
1670 LL=LU: LPRINT "A1","A","AA","AC","AL","AM","AT","B0","B2","B4","B5","B6","B9","BC","BE","BF","BU","C1","C2","D1","D","DA","DX",
"F1","FA","FC","FD","FI","FS","H","I1","I","IS","K0","K2","K5","K6","K7","K9","K","KE","LA","LA(FT)","LB","LC","LP","LX",
1680 LPRINT "M1","M2","MF","MU","N","NA","ND","NO","P","PC","PI","PK","PL","PW","P1","SM","T1","T","TA","TE","TP","TQ","TR","TS","TT
","TW","TX","V","W1","W","WA","WB","WC","WH","WP","WX","WW","WY","WZ","XB","ZI",CHR$(10),CHR$(10)
1690 IF ZX=0  THEN 1710 ELSE 1700
1700 LPRINT"********* THERE IS NO SOLUTION FOR TW="TW " AND N="N,CHR$(10),CHR$(10):ZX=0:ZY=1:GOTO 1510
1710 LL=LU: LPRINT A1(N),A(N),AA(N),AC(N),AL(N),AM(N),AT(N),B0(N),B2(N),B4(N),B5(N),B6(N),B9(N),BC(N),BE(N),BF(N),BU(N),C1(N),C2(N),
D1(N),D(N),DA(N),DX(N),F1(N),FA(N),FC(N),FD(N),FI(N),FS(N),H(N),I1(N),I(N),IS(N),K0(N),K2(N),K5(N),K6(N),K7(N),K9(N),
1720 LPRINT K(N),KE(N),LA(N),LA(N)/12,LB(N),
1730 LPRINT LC(N),LP(N),LX(N),M1(N),M2(N),MF(N),MU(N),N(N),NA(N),ND(N),NO(N),P(N),PC(N),PI(N),PK(N),PL(N),PW(N),P1(N),SM(N),T1(N),T(
N),TA(N),TE(N),TP(N),TQ(N),TR(N),TS(N),TT(N),TW(N),TX(N),V(N),W1(N),W(N),WA(N),WB(N),WC(N),WH(N),WP(N),WX(N),
1740 LPRINT WW(N),WY(N),WZ(N),XB(N),ZI(N),CHR$(10),CHR$(10): GOTO 1510
1750 GOTO 1770
1760 IF ZW<>0  THEN 1780
```

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1770 NEXT N
1780 IF ZH<>0 THEN 1800
1790 S1=35000:E=1.01E+07:ZH=ZH+1:TN=.01:TM=.05:DM=2:RH=.1:GOTO 80
1800 IF ZH<>1 THEN 1820
1810 S1=4E+07: E=4E+07:WL=6.6E-04:ZH=ZH+1:TN=.01:TM=.05:DM=2: RH=.063:IF ZU= 3 THEN 1830
1812 GOTO 80
1820 IF ZH<>2 THEN 1840
WL=3.3E-04:TL=.006:ZH=ZH+1:TN=.01:DM=2:TM=.05:IF ZU=3 THEN 1850
1832 GOTO 80
1840 IF ZH<>3 THEN 1860
1850 TL=.125:ZH=.65:ZH=ZH+1: TN=.01:TM=.05:DM=2:GOTO 80
1860 IF ZH<>4 THEN 1890
1870 ZH=.47:WN=15:ZH=ZH+1:TN=.01:TM=.05:DM=2:GOTO 80
1880 END
1890 PRINT "PROGRAM PREMATURELY FINISHED - K2 CALCULATION IS NOT VALID"
1900 PRINT "PROGRAM PREMATURELY FINISHED - K3 CALCULATION IS NOT VALID"
1910 PRINT "A IS TOO LARGE"
```

APPENDIX 5. OPTOTV COMPUTER SYMBOLS AND LINE NUMBER CROSS REFERENCES

```
 0  100 140/2 260 410 430 500 580 710 780 990 1540 1570
    1590 1690 1700 1760 1780
 1  60 70/2 75 100/3 135 260 280 320 330/2 340 350 360
    380 390 410 430 480 500 510 520/3 530 560 590 640
    650 700 710 720/2 730/2 740 760 820/2 830/2 890/3
    910/2 950 960 1010 1040 1050/2 1052 1210 1220 1230
    1240 1250 1260 1264/2 1275 1280 1285 1295 1320/2
    1330/2 1620 1660 1700 1790 1800 1810 1830 1850 1870
 2  60 70 100/2 120 130 135 260/5 270 300/2 320 330 370
    380/2 390 410 420/5 450/2 460/6 480 520 570/2 800
    830/2 870/2 880 890/7 900 910 930/3 950 960/4 1100
    1140 1190 1250 1290 1320 1460 1560 1600 1790 1810
    1820 1830 1850 1870
 3  60 70 130 260 320 330 390 420 450 890/4 910/3 930
    960 1810 1830 1840
 4  260 320 410 460/2 480 520 1810/3 1830 1860
 5  160 320 360 380 390 1000 1130 1170 1230 1290/2
 6  160 260 330 390/2 910
 7  360 380 390 1790 1810/2
 8  890 960
 9  130 320 1060 1120 1150 1210 1290
10  70/6 75/2 90/2 110/2 360 380 390 410 540 750 1280
    1290 1600/2 1700/2 1740/2
12  410/2 1300/3 1720
15  1870
18  810
20  260
25  1290
45  110/2
90  70/2 1790 1812 1832 1850 1870
100  200/3 220 230/3 250 1550
120  110/2
130  120
144  300
170  1460 1600
200  1560
290  10 1500
300  270
340  1340
360  350
370  350
372  100
380  370
387  450/2
390  370
400  360 380 390
410  360 380 390
440  420
450  1280
510  570
520  550
540  530
560  530
570  560
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580  560
590  700
660  650
710  650 770
720  750
750  740
760  740
770  760
780  760
844  100
870  470
890  870
900  870
920  910
930  910
960  890
990  980
1000  170/2 190 990
1010  990
1020  1010
1030  1010
1040  980
1070  1060
1080  1060
1090  1080
1100  1080
1110  1100
1120  1100
1160  1150
1170  1150
1180  1170
1190  1170
1200  1190
1210  1190
1220  1210
1230  1210
1240  1220
1250  1230
1260  1250
1261  1052
1270  1070 1090 1110 1120 1130 1140 1160 1180 1200 1220
      1240 1250 1260 1261 1262 1263
1340  1330
1350  1330
1360  1040
1370  1350 1360 1380
1380  1320
1390  1370
1450  1440
1470  1440
1490  1350 1360 1370 1390
1500  1000 1020 1030
1510  1051 1660 1700 1740
1530  1000 1020 1030
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 1560  1550 1570
 1570  1550
 1590  1540
 1600  1530
 1620  1520 1590
 1640  1620
 1650  440
 1660  1650
 1670  1430 1480 1660
 1700  1690
 1710  1450 1490 1690
 1760  1630
 1770  1750
 1780  1760
 1800  1790
 1820  1800
 1830  1810
 1840  1820
 1850  1830
 1860  1840
 1880  1860
 1890  540
 1900  750
 1910  420
 2499  1270 1275
 2500  1270 1275 1280
 3600  1290
10502  100
13500  1220 1240 1260 1264
14000  1160 1220
14100  1180 1240
14400  1200 1260
14500  1120 1160
14600  1263 1264
15300  1070 1120
15700  1130 1180
16700  1090 1130
17100  1140 1200
17300  1070
17700  1110 1140
17900  1090
18400  1110
18500  1262 1263
18900  1261 1262
19000  1261
35000  1790
40000  1275 1285
    A  260 270 330 420/3 430 450 890/4 960 1390 1390( 1710(
   A1  890/5 1420 1420( 1710(
   AA  910/2 930 1390 1390( 1710(
   AC  300 1390 1390( 1710(
   AL  460/4 480/8 490/8 520/4 590/9 610/9 620/9 630/9 660/4
       670/4 680/4 690/4 720/2 730/6 820/5 830/2 1390 1390(
       1710(
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AM  890/3 1420 1420( 1710(
AT  890/2 1420 1420( 1710(
B   40 110 480/9 490/8 500/2 520/7 600/4 610/4 620/4
    630/4 640/4 730/7 820/7
B0  460/4 480/8 490/8 500/2 520/5 540/2 570/2 600/10
    610/10 620/10 630/10 640 660/6 670/6 680/6 690/6
    700 720/3 730/9 750/2 770 900 820/9 830/2 1390 1390(
    1710(
B1  40 110 570 570/22 580 600/3 610/3 620/3 630/3 640/4
    660/4 670/4 680/4 690/4 700 720 800 800/% 810/2 820/2
    830/4
B2  910 930/3 1390 1390( 1710(
B4  590 590 700 720/4 730/3 1390 1390( 1710(
B5  500/4 540 900 1390 1390( 1710(
B6  720 1390 1390( 1710(
B9  640/2 720 1390 1390( 1710(
BC  700/2 1390 1390( 1710(
BE  450 460 640/4 700/2 730/2 820/3 830 1390 1390( 1710(
BF  450 460/2 480 520 1390 1390( 1710(
BP  40 110 590 600/2 610/2 620/2 630/2 660/4 670/4 680/4
    690/4 810/2
BT  590 600/2 610/2 620/2 630/2 640/5 720/4 730/3 750
    820/2 830
BU  890/3 1420 1420( 1710(
C1  260/3 1390 1390( 1710(
C2  260 430 1390 1390( 1710(
CD  40 110 450
D   450/2 480/2 520/2 640/4 700/2 730/2 820/2 1390 1390(
    1710(
D1  210/% 220 220/% 260/3 330 420 450 890 960/4 1390
    1390( 1450 1460 1480 1480( 1490 1490( 1550( 1570/%
    1570( 1580/% 1600/2 1710(
D2  40 110 260/2 330
DA  420/2 1420 1420( 1710(
DB  40 110 420
DC  120 140 1450
DD  40 100 110 150 200 200/% 210/% 1460 1540 1560/2 1600
DM  40 100 110 120 140 150 200 200/% 210/% 1460 1560
    1600 1790 1810 1830 1850 1870
DT  40 110 930/2
DV  40 110 340
DX  120 140 150 200 200/% 210/% 1390 1390( 1550/% 1560/2
    1570/% 1600 1710(
DY  120 140
E   40 110 260 450 890 960 1280 1790/2 1810/4 1830
EE  40 110 960
EN  40 110 900
F1  460 490/4 490/4 520/2 610/8 630/8 670/4 690/4 720/2
    730/2 820/2 830 1390 1390( 1710(
FA  930/2 1390 1390( 1710(
FB  40 100 110 330
FC  930/2 1390 1390( 1710(
FD  930/2 1390 1390( 1710(
FI  460 480/4 490/4 520/2 600/8 620/8 660/4 690/4 730/4
    820/2 1390 1390( 1710(
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FS 420 430 1390 1390(1710(
G 40 110 450 1320/2 1330
G1 480 500
G2 480 500/2
G3 480 500
G4 490 500
G5 490 500
GE 40 110 890
H 450/2 930 940/2 1400 1400(1710(
H1 600 640
H2 600 640/2
H3 610 640
H4 610 640
H5 620 640
H6 620 640
H7 630 640
H8 630
I 890/3 1420 1420(1710(
I1 960/2 1400 1400(1710(
IS 1280 1290 1320/2 1330 1400 1400(1710(
J1 660 700
J2 670 700
J3 680 700
J4 690 700
K 450/3 480 500/2 520/3 640/4 700/2 730/2 820/2 1400
1400(1720(
K0 790/2 860/2 870 880 900 910 930/6 1400 1400(1710(
K1 40 110 260
K2 520 530 570 580 790/2 1400 1400(1710(
K3 730 740 770 780
K4 720 730
K5 770 790/2 1400 1400(1710(
K6 780 1400 1400(1710(
K7 580 1400 1400(1710(
K8 820 830/2 840/2
K9 570 1400 1400(1710(
KA 890/2
KB 890/2
KC 890/2
KE 840/2 860/2 1400 1400(1720(
KP 40 110 1300/2
KQ 40 110 1300
KS 40 110 1310
KT 40 110 1310
KU 320/2 330
KV 320/2 330
KX 710/2 760 780
KY 590/2 650 710
KZ 510/2 560 590
LA 290 300 380/2 390/2 430 450 880 890/4 900 910 930/10
1370/2 1400 1400(1470 1480/2 1480(1490 1490(1500
1520 1530/2 1720(2
LB 420/2 430/3 1400 1400(1720(
LC 430/3 1400 1400(1730(

C – 3

LD 40 100 110 290 1370 1500 1520 1530

LF 40 110 420/2

LL 1430 1440 1500 1530 1670 1710

LN 40 100 110 120 150 330

LP 410/2 420/2 430/2 1400 1400(1730(

LQ 40 100 110 420/2 430/2

LU 420 430/2 1530 1676 1710

LX 260 280 290 420/2 430/2 1370 1400 1400(1520 1530
1730(

LY 120

LZ 150 260/2 280 290 1370 1430 1440 1480 1500/2 1530

M1 890/2 930 940 1400 1400(1730(

M2 930 940 1400 1400(1730(

MF 96J 910/2 1400 1400(1730(

MH 40 110 330

MU 340 360/3 380/3 390/3 400 1050 1320 1330/2 1400 1400(
1730(

MV 40 110 340

MZ 360/2 380/2 390/2

N 130 135 160/2 1060 1080 1100 1120 1130 1140 1150
1170 1190 1210 1230 1250 1290/3 1310 1390/25 1400/27
1400(1410/25 1420/10 1480/6 1480(1490/6 1490(1550
1570 1700 1710/39 1720/5 1730/39 1730(1740/5 1770

NA 910/2 930 1400 1400(1730(

ND 930/3 1400 1400(1730(

NO 890 1420 1420(1730(

P 890 940/3 950/2 990 1350 1360 1390 1400 1400(1730(

PC 960 970/2 980 1350 1360 1390 1400 1400(1730(

PI 40 110 300 330/2 380/2 450 500 540/2 570/2 750/2
770 800 980 990/4 960/3

P! 940/3 1400 1400(1730(

PK 960 970/2 1410 1410(1730(

PL 1310 1320 1330 1410 1410(1730(

PP 1300/2 1310

PW 360/2 380/2 390/2 410 1290 1410 1410(1730(

Q6 1550/22

Q1 960/2 1410 1410(1730(

RH 40 110 330 1790 1810

RN 40 110 330

RS 40 110 260

S1 40 110 960 1790 1810

S! 890 910/2 1410 1410(1730(

SF 40 110 910

T 500/2 520/8 540/2 570/2 640 660/4 670/4 680/4 690/4
720/4 730/12 750/3 770/2 810 820/10 830/3 850 1730(

T0 40 110 310

T1 180/% 190 190/% 330 450 890 960/2 1410 1410(1460/2
1480 1480(1490 1490(1570/% 1600/2 1610/% 1730(

T2 40 110 330

T3 1070 1090 1110 1120 1130 1140 1160 1180 1200 1220
1240 1260 1261 1262 1263 1264 1270/2

T4 1070 1090 1110 1120 1130 1140 1160 1180 1200 1220
1240 1260 1261 1262 1263 1264 1270

TA 310 330 920 1410 1410(1730(

```
TB  120 140 1430 1480 1660
TC  120 140
TD  40 100 110 150 170 170/% 180/% 1460/2 1590 1600/2
TE  330/2 880 900 910 1410 1410( 1730(
TF  40 110 230 [illegible] 240/%
TG  40 110 [illegible]
TL  40 110 [illegible] 1630 1850
TM  40 100 110 120 140 150 170 170/% 180/% 1460 1570/%
    1600 1790 1810 1830 1850 1870
TN  40 110 120 140 230 230/% 240/% 1530 1600 1790 1810
    1830 1850 1870
TP  1050/2 1051 1060/2 1080/2 1100/2 1120/2 1130/2 1140/2
    1150/2 1170/2 1190/2 1210/2 1230/2 1250/2 1261/2
    1262/2 1263/2 1264/2 1270/2 1275 1280 1285 1295 1410
    1410( 1730(
TQ  1300/4 1310 1410 1410( 1730(
TR  1290/3 1300 1410 1410( 1730(
TS  1290 1295 1300 1410 1410( 1730(
TT  1270/3 1275/3 1280/2 1285 1290 1410 1410( 1730(
TU  120 140
TW  240/% 250 250/% 880 900 910 930/6 1050/2 1410 1410(
    1430 1480/2 1480( 1490 1490( 1510/% 1530 1600 1660
    1700 1730(
TX  120 140 150 170 170/% 180/% 1410 1410( 1460 1600
    1730(
TY  40 100 110 230 230/% 240/%
TZ  40 110 310
V   1270 1295 1320/2 1330 1410 1410( 1730(
V1  1070 1090 1110 1120 1130 1140 1160 1180 1200 1220
    1240 1260 1261 1262 1263 1264 1270/2
V2  1070 1090 1110 1120 1130 1140 1160 1180 1200 1220
    1240 1260 1261 1262 1263 1264 1270
W   880/2 890 1420 1420( 1730(
W1  330 380 390 880 900 910 930/2 1410 1410( 1730(
WA  330/4 380 390 930/2 1410 1410( 1730(
WB  380/3 390/2 1410 1410( 1730(
WC  380/3 390/2 1410 1410( 1730(
WH  380/2 390/2 1410 1410( 1730(
WL  40 110 330 1810 1830
WN  40 110 330 1870
WP  330/2 1420 1420( 1730(
WS  40 110 360/2 380/2 390/2 1020 1030/2 1050/2 1270
    1280 1320/2 1330/2 1360 1380/2
WT  40 100 110 390 450 930/2
WU  40 100 110 140
WV  140 360 1340
WW  360/3 380/3 390/6 450/4 1000 1020 1030/2 1050/2 1340/2
    1350 1360 1380/2 1410 1410( 1450 1740(
WX  360/2 380/2 390/2 1030 1320 1330 1380 1410 1410(
    1730(
WY  1000 1030 1320/2 1330/2 1340 1350 1380 1410 1410(
    1450 1740(
WZ  360 380 390 450/4 1410 1410( 1740(
XB  890/4 1420 1420( 1740(
ZH  40 100 110 380 390 1850 1870
```

ZI 330 1390 1390(1740(

ZO 25 75 135 1050 1052 1275 1285 1295

ZU 30 70/3 100/2 270 280 320/2 330/2 350 370 420 430
870 950 1330 1810 1830

ZW 1760 1780 1790/2 1800 1810/2 1820 1830/2 1840 1850/2
1860 1870/2

ZX 140 1660 1690 1700

ZY 140 1700

ZZ 20 60($3 70 70($ 410/2 990 1010 1040 1320 1620

APPENDIX 6

SUMMARY OF OPTOTV PROGRAM INPUT-OUTPUT PARAMETER CATEGORIES

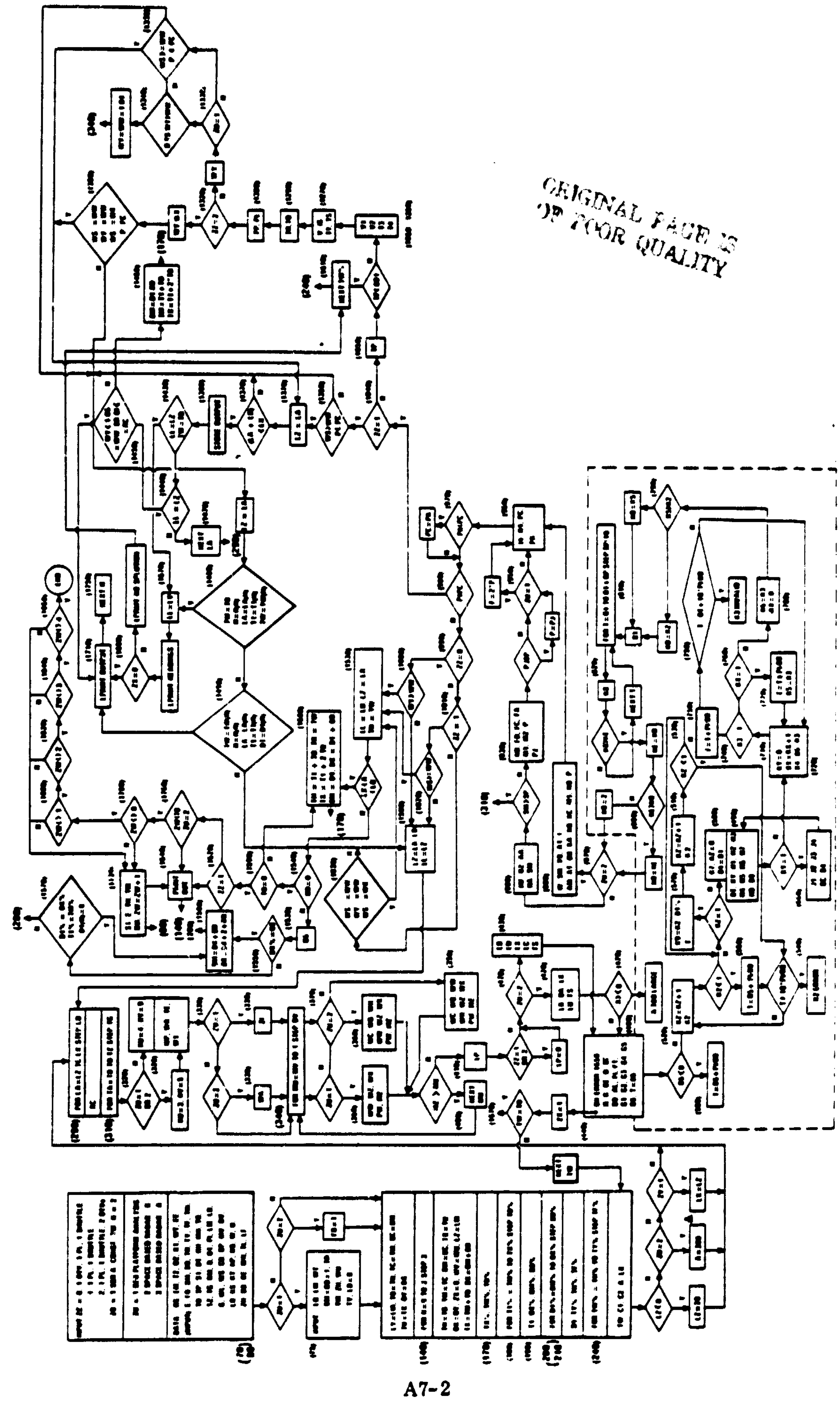
	INPUT	OUTPUT
PROGRAM OPTIONS	ZU = 1 GEO Platform Analysis ZU = 2 SBR-R Analysis ZU = 3 SBR-A Analysis ZZ = 0 1 Payload - 1 OTV - 1 Shuttle ZZ = 1 1 Payload - 1 Shuttle ZZ = 2 1 Payload - 1 OTV - 2 Shuttles ZO = 1 SBR, Const. TW, N = 2	
GENERAL		
• Payloads	D2, G, LD, LM, T2, ZH	D1, DX, I1, LA, LB, LX, M1, P, PC, R1, T1, TX, WA, WB, WH, WW
- primary struts	TM, TD, DM, DD	
construction materials	E, S1, RH, RM, SP	
• Shuttle	LQ, RS, WS	
• OTV	N, KP, KQ, KS, KT	IS, LP, MU, PL, PP, PW, TP, TQ, TR, TS, TT, TW, V, WX, WU, WZ
- final T/W	TN, TF, TY	
- mass fraction	MU, DV	
Geoplatform Peculiar	FB, K1, WT	C1, C2, H, K, PJ, PK, Z1
SBR-A Peculiar	DT, EE, EM, FB, LF, K1, MH, TL, WL, WT	A, AC, C1, C2, FA, FC, FD, FS, H, K, LC, M2, ND, PJ, PK, TA, TE, W1, WC
- membrane	TØ, TG, TZ	AA, B2, MF, NA, SM

Summary of OPTOTV Program Input-Output Parameter Categories (continued)

	INPUT	OUTPUT
- dynamics	B, B1, BP, CD	AL, BØ, B2, B4, B5, B6, B9, BC, BE, BF, D, F1, FI, KØ, K2-K9, KE, T
• SBR-R Peculiar	DB, FB, GE, LF, WL, WN	A1, AC, AM, AT, BU, DA, FS, I, KA, KB, KC, NO, W, W1, WC, WP, XB

APPENDIX 7

OPTOTV
COMPUTER PROGRAM FLOW DIAGRAM



APPENDIX 8

SOLAR ELECTRIC PROPULSION SYSTEM

SEPS Power Module

The following is an outline of the more significant algorithms and input data that could be used to expand the OPT OTV computer program to include structural models of SEPS type Power Modules. Material from AEC-Able Engineering Company, Inc. is the source o. much of this information.

- The Folded-Container-Design Configuration, shown in Figure A8-1 will be used to establish the stowed state configuration of the power module.

- Two automatically deployed ABLE booms are considered: (1) The ACR system which is a lattice boom having articulated longerons, and (2) the CC system which is a lattice boom having continuous coilable longerons. Both systems are sized on the basis of strength or simple G loading considerations.

- Following are sizing algorithms for the ACR system:

  a) Bending stiffness $EI = 1.5\ C_1\ E\ A_\ell R^2$

E	=	Youngs Modulus
C_1	=	0.9, joint flexibility - caused reduction factor
A_ℓ	=	Longeron cross-section area
R	=	Boom radius

  b) Bending strength $M_{CR} = 1.5\ P_{CR}\ R$

P_{CR}	=	Longeron strength based on Euler column buckling and bay length $L_B = 1.4R$ = column length

  c) Boom weight $W_B = 3\ C_2\ \rho A_\ell L$

L	=	Boom length
C_2	=	3.0, empirical coefficient
ρ	=	Material density

d) Retracted height of boom $H_B = .75\ Ld/R$

d = Longeron diameter

e) Height of canister $H_{CAN} = H_B + 3R$

f) Weight of canister $W_{CAN} = K_1 Ld/14 + K_2\ 3R^2/5$

R	5"	10"	18"	
K_1	1	.40	.30	empirical coefficients
K_2	1	.75	.50	

- Following are sizing algorithms for the CC system:

a) $EI = 1.0\ C_1\ E\ A_\ell\ R^2$

b) Same but based on $L_B = 1.1\ R$

c) $W_B = 9\ \pi \rho R^2\ \epsilon^2\ L$

ϵ = Fractional elongation allowable in construction material

d) $H_B = (3L/\pi)\ (\epsilon + .005)$

e) Same

f) Same

- The following materials and minimum gages should be considered for the ACR system

t_{min} = Minimum tubular wall thickness

	E psi	ρ lbs/in^3	t_{min} in.
Steel	2.8×10^7	.280	.010
Titanium	1.6×10^7	.160	.010
Alum	1.0×10^7	.100	.010
G/E	4.0×10^7	.055	.025

- The following material are to be considered for the CC system:

  S - glass epoxy

  ϵ = .03

  E = 7.5×10^6 psi

  ρ = .072 #/in^3

  The ϵ = .03 is based on prestressing the coiled longerons to minimize the coiling radius. The longerous have a rectangular cross-section to maximize packaging efficiency.

- The unit area weights of the SEPS blanket as well as the weights of the blanket canisters will be based on extrapolation of state-of-the-art SEPS weights.

- This study will be like the SBR-A, SBR-R and GEO Platform trade studies generated by the OPT OTV computer program. The objective of the SEPS power module study will be to select the optimum payload and OTV parameters that maximize the area (or in this case power generating capability) of the power module.

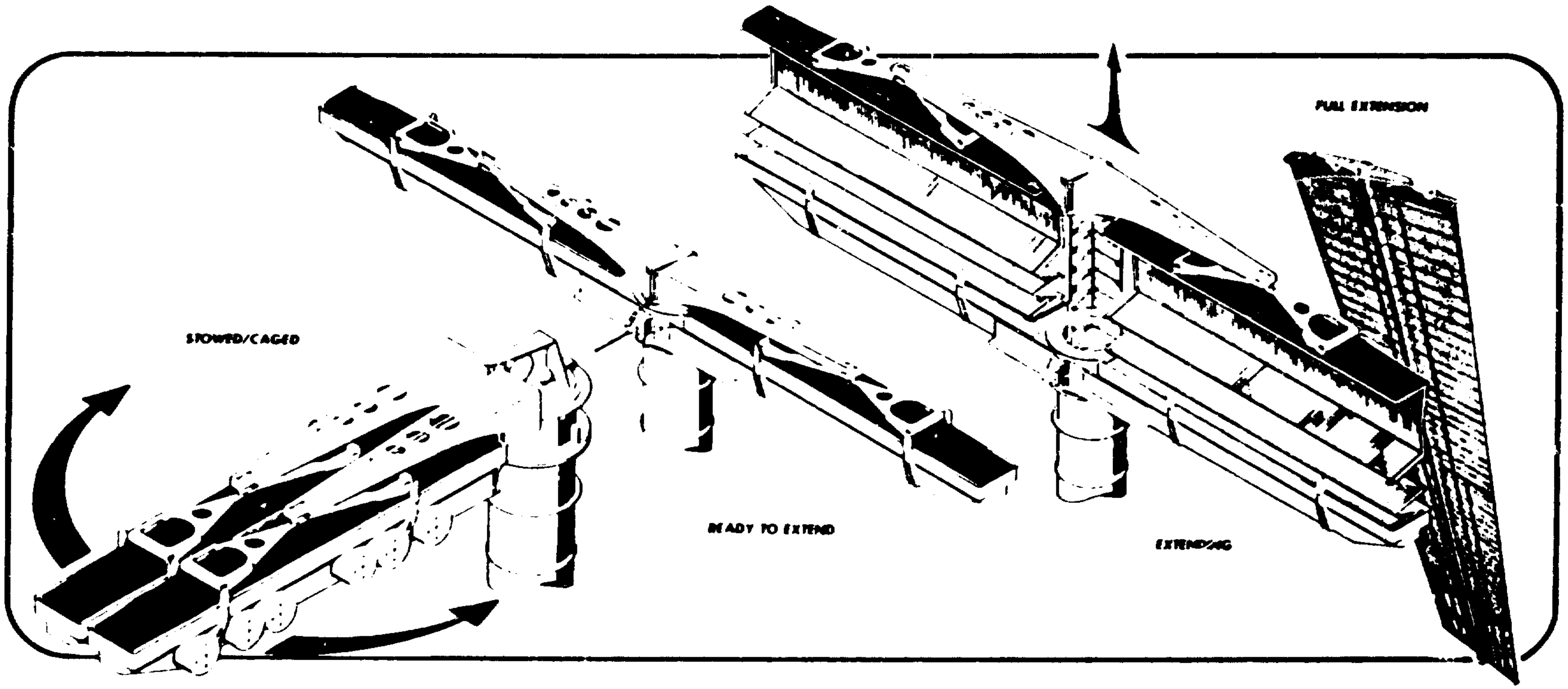


Figure A8-1. SEPS power module

APPENDIX 9-1. SPACE BASED RADAR-A ANALYSIS (One Payload Using Entire Shuttle Cargo Bay)

OPTOTV/OOA - 1 PAYLOAD, 1 SHUTTLE

B1	B	BP	CD	D2	DD	DM	DT
DV	E	EE	EM	FB	G	K1	LD
LM	LQ	MM	MV	PI	RM	RM	RS
S1	SP	T2	T0	TD	TF	TG	TM
TN	TY	TZ	WL	WS	WT		

100	1	1	.014	1	5	2	3
.01	4E+07	.107	300000	3.218	32.17	2	40
4300	684	6	.05	3.14159	063	0513	09
37000	3330	.025	2E-03	.01	.04	9E-03	05
.01	.41	02	3.3E-04	60000	1		

A	AA	AC	AL	B0	B2	B4	B5
B6	B9	BC	BE	BF	C1	C2	[illegible]
D	DX	F1	FA	FC	FD	FI	FS
H	I1	IS	K0	K2	K5	K6	K7
K9	K	KE	LA	LA(FT)	LB	LC	LP
LX	M1	M2	MF	MU	N	NA	ND
P	PC	PJ	PK	PW	R1	SM	T1
T	TA	TE	TP	TT	TW	TX	V
W1	WA	WB	WC	WH	WX	WW	WY
W2							

53.766	0936992	1.24423E+06	1.51639E-04	356793	0743691	0	0
0	0	0	.356793	0174149	10	6.8	2
2.55739E-03	2.5	8.50012E-04	50.408	100.816	1306.97	-1.57037	997785
93.1227	15700	0	2	0	0	0	0
0	1.07347	0	5340	445	684	675.372	0
5400.22	750790	405031	1.37106E-04	.05	9	0	254095
8140.38	9579.13	4358.02	9579.13	5282.05	700	439.62	05
0	2E-03	4.50997E-04	0	0	01	06	0
3.53547E-04	332116	1773.5	26192	16945.9	6215.12	57784.9	0
3474.16							

52.5315	150436	852436	4.01666E-04	000695	119401	0	0
0	0	0	000695	0283431	11.5	0	2.5
5.98176E-03	3	9.04556E-04	172.676	345.351	2780.44	-1.57034	984094
90.9846	797671	0	2	0	0	0	0
0	5.8729	0	4420	368.333	684	673.12	0
4491.44	2.59249E+06	1.68649E+06	5.67424E-04	05	9	0	655937
20493.7	32267.4	18536	32267.4	1625.55	805	1135.83	13
0	2E-03	4.509?7E-04	0	0	05	14	0
3.53547E-04	823362	3639.26	17944.5	18301.5	1912.41	50887.6	0
3832.1							

51.306	.173085	610324	5.36604E-04	1.24731	.137378	0	0
0	0	0	1.24731	.0327599	13	9.2	3
8.83210[illegible]-03	3.5	8.6042E-04	222.537	445.074	3109.59	-1.57037	.980473
88.8619	1.59043	0	2	0	0	0	0
0	12.8035	0	3740	311.667	684	670.643	0
3814.49	3.33099E+06	2.34222E+06	8.6423E-04	.85	9	0	.868982
37405	45791.1	26357.9	45791.1	4519.25	1.062	1505.43	.15
0	2E-03	4.58997E-04	0	0	.09	.16	9
3.53547E-04	1.09628	4100.00	12047.8	17229	5316.77	54683.2	0
3381.06							
50.0893	.186132	452407	6.75262E-04	1.63372	.147733	0	0
0	0	0	1.63372	.0367495	14.5	10.4	3.5
.0120408	4	8.26657E-04	238.271	476.543	3093	-1.57038	.977435
86.7547	2.69392	0	2	0	0	0	0
0	23.7962	0	3220	268.333	684	668.566	0
3294.34	3.6143E+06	2.68043E+06	1.07477E-03	.85	9	0	1.00542
41661.1	50017	30988.8	50017	7131.16	1.239	1742.31	.16
0	2E-03	4.58997E-04	0	0	.13	.17	0
3.53547E-04	1.33644	4303.34	9523.53	16260.8	8389.59	51610.4	0
3697.56							
50.0893	.203543	452407	6.75262E-04	1.63372	.161553	0	0
0	0	0	1.63372	.0367495	14.5	10.4	3.5
.0120408	4	8.26657E-04	311.586	623.171	3693.38	-1.57038	.977435
96.7547	2.69392	0	2	0	0	0	0
0	23.7962	0	3220	268.333	684	668.566	0
3294.34	4.69406E+06	3.51564E+06	1.40547E-03	.85	9	0	1.20317
54116.4	50017	40523.8	50017	7131.16	1.239	2005.87	.16
0	2E-03	4.58997E-04	0	0	.17	.17	0
3.53547E-04	1.33644	4303.34	9523.53	16260.8	8389.59	51610.4	0
3697.56							
50.0893	.217489	441237	9.50062E-04	2.077	.172621	0	0
0	0	0	2.077	.0437736	14.5	10.4	3.5
.0137168	4	9.22545E-04	375.397	750.793	4159.24	-1.57034	.965293
86.7547	3.3674	0	2	0	0	0	0
0	30.9818	0	3180	265	684	660.26	0
3294.34	6.24936E+06	4.96739E+06	1.7146E-03	.85	9	0	1.37454
72034.8	72521.3	56105.2	72521.3	583.392	1.229	[illegible]	.2
0	2E-03	4.58997E-04	0	0	.21	.21	0
3.53547E-04	1.64211	5221.9	9288.39	18687.9	686.332	59313.7	0
2906.13							
48.8815	.221455	346989	1.10074E-03	2.48836	.175769	0	0
0	0	0	2.48836	.0469199	16	11.6	4
.0171363	4	8.8471E-04	351.443	702.886	3822.7	-1.57035	.978377
84.6628	5.02655	0	2	0	0	0	0
0	40.198	0	2820	235	684	669.21	0
2882.32	6.01739E+06	4.84477E+06	1.81011E-03	.85	9	0	1.42539
71074.8	84023.3	57224.2	84023.3	2862.83	1.416	2472.27	.2
0	2E-03	4.58997E-04	0	0	.25	.21	0
3.53547E-04	1.86044	5246.44	7304.38	17042.9	3368.04	56632	0
3181.65							

48.0815	.232687	346989	1.20569E-03	2.63625	.184683	0	0
0	0	0	2.63625	.0491058	16	11.6	4
0175595	4.5	9.14702E-04	407.674	815.348	4215.7	-1.57034	.978377
84.6628	5.27700	0	2	0	0	0	0
0	50.6079	0	2820	235	684	669.21	0
2082.32	7.16241E+06	5.82133E+06	2.09973E-03	.85	9	0	1.57448
84599.3	88224.5	68759	88224.5	1029.05	1.416	2731.74	.21
0	2E-03	4.58997E-04	0	0	.29	.22	0
3.53547E-04	1.94777	5492.72	7304.38	18522.7	1210.65	58789.4	0
2960							

47.6826	.233367	272707	1.37512E-03	3.13448	.185224	0	0
0	0	0	3.13448	.0524427	17.5	12.8	4.5
.0217654	4.5	8.77413E-04	364.595	729.19	3758.97	-1.57036	.981147
82.5862	7.51479	0	2	0	0	0	0
0	77.7551	0	2500	208.333	684	671.105	0
2548.04	6.63644E+06	5.54433E-06	2.11821E-03	.85	9	0	1.58376
80357.7	100328	67133.9	100328	3343.1	1.593	2747.89	.21
0	2E-03	4.58997E-04	0	0	.33	22	0
3.53547E-04	2.17702	5442.55	5740.71	17664.9	3933.06	56066.9	0
3239.7							

47.6826	.242439	272707	1.37512E-03	3.13448	.192424	0	0
0	0	0	3.13448	.0524427	17.5	12.8	4.5
0217654	4.5	8.77413E-04	408.788	817.576	4053.16	-1.57036	981147
82.5862	7.51479	0	2	0	0	0	0
0	77.7551	0	2500	208.333	684	671.105	0
2548.04	7.42704E+06	6.21637E+06	2.37496E-03	.85	9	0	1.71006
89930.7	100328	75271.3	100328	3343.1	1.593	2967.83	.21
0	2E-03	4.58997E-04	0	0	.37	22	0
3.53547E-04	2.17702	5442.55	5740.71	17664.9	3933.06	56066.9	0
3239.7							

47.6826	249533	264051	1.62773E-03	3.53116	.190055	0	0
0	0	0	3.53116	.0570565	17.5	12.8	4.5
0233361	5	9.21922E-04	438.602	877.204	4221.99	-1.57034	.965449
82.5862	8.23049	0	2	0	0	0	0
0	89.3824	0	2460	205	684	660.367	0
2548.04	8.41035E+06	7.13705E+06	2.58961E-03	.85	9	0	1.81227
101837	109883	86419.3	109883	618.352	1.593	3145.89	.23
0	2E-03	4.58997E-04	0	0	.41	.24	0
3.53547E-04	2.37352	5838.86	5558.48	18674.9	727.473	59272.5	0
2910.36							

APPENDIX 9-2. SPACE BASED RADAR-A ANALYSIS
(Baseline Configuration)

OPTOTV/OOA - 1 PAYLOAD, 1 OTV, 1 SHUTTLE

01	B	BP	CD	D2	DD	DM	DT
DV	E	EE	EM	FB	G	K1	KP
KQ	KS	KT	LD	LM	LQ	MH	MV
PI	RH	RM	RS	S1	SP	T2	T0
TD	TF	TG	TM	TN	TY	T2	NL
NS	NT						

100	1	1	014	1	1	2	3
01	4E+07	107	300000	3.218	32.17	2	21
5	15	4.1	10	1700	604	6	05
3.14159	.063	0513	80	37000	3330	025	2E-03
5E-03	04	9E-03	05	01	41	02	3.2E-04
60000	1						

A	AA	AC	AL	B0	B2	B4	B5
B6	B9	BC	BE	BF	C1	C2	D1
D	DX	F1	FA	FC	FD	FI	FS
H	I1	IS	K0	K2	K5	K6	K7
K9	K	KE	LA	LA(FT)	LB	LC	LP
LX	M1	M2	MF	MU	N	NA	ND
P	PC	PJ	PK	PL	PW	R1	SM
T1	T	TA	TE	TP	T0	TR	TS
TT	TW	TX	V	N1	NA	NB	NC
NM	NX	NW	NY	N2			

53.766	0704527	224838	4.52165E-04	1.1703	0559183	0	0
0	0	0	1.1703	0300721	10	6.8	2
9.2272E-03	2.1	7.72736E-04	9.10095	18.2179	314.357	-1.57041	684073
93.1227	15700	426.193	2	0	0	0	0
0	13.9744	0	2270	189.167	503.19	287.096	190.81
3978.6	08730.5	41034.6	5.82829E-05	80	9	0	143597
952.935	9579.13	440.651	9579.13	612.611	40099.6	700	248.394
05	0	2E-03	4.58997E-04	3.18339E-03	50.3502	25	25.3502
191.004	01	055	15268.1	3.53547E-04	332116	753.902	4733.01
4260.72	46476.9	13523.1	13594.9	5577.22			

53.766	124907	279292	3.60121E-04	.962832	0991385	0	0
0	0	0	962832	0268373	10	6.8	2
7.94201E-03	2.1	7.48045E-04	56.5754	113.151	1098.81	-1.57042	728755
93.1227	15700	451.347	2	0	0	0	0
0	10.0937	0	2530	210.832	505.511	319.979	178.489
3996.96	490437	271840	3.24792E-04	87	9	0	451063
5352.48	9579.13	2919.16	9579.13	516.389	38320.7	700	782.116
05	0	2E-03	4.58997E-04	0180661	29.4323	25	4.43228
1003.96	05	055	14455.2	3.53547E-04	332116	840.252	5879.31
5026.34	44046.8	15953.2	16002.3	5726.09			

53.5104	.15254	.285955	3.61051E-04	.965006	.121071	0	0
0	0	0	.965006	.0268719	10.3	7.04	2.1
7.85848E-03	2.1	7.48225E-04	104.265	208.53	1655.51	-1.57042	.752661
92.6938	.181839	457.752	2	0	0	0	0
0	10.1361	0	2560	213.333	505.932	336.752	178.068
3846.11	.895049	.511034	5.91559E-04	.87	9	0	.674452
9655.97	10143.1	5513.14	10143.1	507.100	37853.7	.7434	1167.94
.05	0	2E-03	4.58997E-04	.0332195	27.4149	25	2.41406
1993.17	.09	.065	14371	3.53547E-04	.343032	878.162	6019.57
5195.49	43510	16498	16517.2	5656.3			
53.0242	.169229	.255534	4.46333E-04	1.19286	.134317	0	0
0	0	0	1.19286	.0298775	10.9	7.52	2.3
9.71162E-03	2.4	7.48344E-04	134.583	269.166	1923.97	-1.57042	.761985
91.6379	.286678	458	2	0	0	0	0
0	15.4803	0	2420	201.667	506.066	343.209	177.934
3568.32	1.15049E+06	.692739	8.07745E-04	.87	9	0	.830578
12527.4	13529.6	7543.06	13529.6	503.613	37704.3	.8142	1438.78
.06	0	2E-03	4.58997E-04	.0483074	26.655	25	1.65496
2898.45	.13	.06	14287.2	3.53547E-04	.415082	1004.5	5379.19
5249.6	43338.2	16661.8	16682.8	5633.97			
52.7777	.181948	.230820	5.29178E-04	1.41407	.144412	0	0
0	0	0	1.41407	.0325324	11.2	7.76	2.4
.011511	2.5	7.48447E-04	158.972	317.944	2111.76	-1.57042	.754401
91.4109	.380007	458	2	0	0	0	0
0	21.7482	0	2300	191.667	506.163	338.173	177.837
3442.54	1.36361E+06	.855167	1.0039E-03	.87	9	0	.960572
14917.4	16579	9355.2	16579	501.777	37596.6	.8496	1664.43
.07	0	2E-03	4.58997E-04	.0634764	26.2559	25	1.25508
3808.58	.17	.07	14202.9	3.53547E-04	.480581	1105.34	4858.94
5288.6	43214.4	16785.6	16834.6	5617.88			
52.5315	.19177	.207363	6.22957E-04	1.66444	.152208	0	0
0	0	0	1.66444	.0352975	11.5	8	2.5
.0135473	2.6	7.4855E-04	176.42	352.841	2221.78	-1.57042	.745239
.46	.490874	458	2	0	0	0	0
	30.1229	0	2100	181.667	506.248	331.991	177.752
3324.24	1.52827E+06	.994329	1.17541E-03	.87	9	0	1.06749
16797	19856.9	10928.5	19856.9	500.645	37502.5	.885	1850.11
.08	0	2E-03	4.58997E-04	.0787412	26.0099	25	1.00989
4724.47	.21	.08	14118.1	3.53547E-04	.550447	1199.98	4365.15
5322.66	43106.3	16893.7	16987.6	5603.82			
52.2857	.202934	.205464	6.37122E-04	1.70172	.161069	0	0
0	0	0	1.70172	.0356966	11.8	8.24	2.6
.0139461	2.6	7.488E-04	208.102	416.204	2474.27	-1.57042	.759589
.5588	.552166	458	2	0	0	0	0
	31.4664	0	2170	180.833	506.424	341.983	177.576
3213.44	1.8043E+06	1.19105E+06	1.39288E-03	.87	9	0	1.19595
19924.1	20767.6	13152.2	20767.6	499.848	37306.4	.9204	2073.32
.08	0	2E-03	4.58997E-04	.0945568	25.8366	25	.836569
5673.41	.25	.08	14030.2	3.53547E-04	.567914	1232.37	4325.19
5393.7	42880.9	17119.1	17146.6	5574.51			

51.7951	211243	194259	6.9311E-04	1.92454	167664	0	0
0	0	0	1.82454	0169624	12.4	8.72	2.8
0140453	2.8	7.48803E-04	228.234	456.467	2604.99	-1.57042	778953
89.7091	689642	458	2	0	0	0	0
0	36.1722	0	2110	175.833	506.427	355.23	177.574
008.08	1.99422E+06	1.33558E+06	1.57107E-03	87	9	0	1.29626
2118.3	22592.8	14887.9	22592.8	499.317	37303.9	9912	2247.86
08	0	2E-03	4.58997E-04	.109698	25.7211	25	721055
6581.87	29	08	13994.6	3.53547E-04	.602847	1272.01	4089.31
5394.58	42878.1	17121.9	17211.6	5574.15			

51.306	218784	185162	7.26275E-04	1.93954	173649	0	0
0	0	0	1.93954	0381123	13	9.2	3
0157788	3	7.48912E-04	247.551	495.102	2726.2	-1.57042	799558
88.8619	848231	458	2	0	0	0	0
0	40.8641	0	2060	171.667	506.494	369.392	177.586
2824.59	2.16484E+06	1.48326E+06	1.74541E-03	87	9	0	1.39104
24361.9	24421.9	16691.8	24421.9	498.899	37228.5	1.062	2412.53
08	0	2E-03	4.58997E-04	.125244	25.6303	25	630277
7514.61	.33	.08	13986	3.53547E-04	63778	1313.83	3897.8
5421.91	42791.3	17208.7	17227.6	5562.87			

50.9182	225861	174533	7.76513E-04	2.07388	178631	0	0
0	0	0	2.07388	0394085	13.6	9.68	3.2
0168731	3.2	7.48849E-04	261.624	523.249	2799.18	-1.57042	816536
88.0172	1.02944	458	2	0	0	0	0
0	46.7289	0	2000	166.667	506.455	380.966	177.545
2658.8	2.29837E+06	[illegible]60119E+06	1.89997E-03	87	9	0	1.47243
26112.7	26254.5	18191.8	26254.5	498.594	37271.8	1.1328	2554.12
08	0	2E-03	4.58997E-04	140157	25.5639	25	563868
9409.43	37	.08	13977.7	3.53547E-04	672713	1345.43	3674.06
5406.21	42841.2	17158.8	17243	5569.35			

50.3319	230938	165915	8.23542E-04	2.19935	183296	0	0
0	0	0	2.19935	0405843	14.2	10.16	3.4
0178928	3.4	7.48896E-04	275.594	551.188	2871.96	-1.57042	835004
87.1749	1.23477	458	2	0	0	0	0
0	52.5472	0	1950	162.5	505.485	393.627	177.516
2509.09	2.43863E+06	1.72525E+06	2.05274E-03	87	9	0	1.55077
27974	28089.9	19790.7	28089.9	498.335	37239.4	1.2036	2690.46
08	0	2E-03	4.58997E-04	15553	25.5077	25	507691
9331.83	41	08	13969.2	3.53547E-04	707646	1379.91	3492.65
5417.93	42804	17196	17258.7	5564.52			

APPENDIX 9-3. SPACE BASED RADAR-A ANALYSIS (Continuation of Appendix 9-2 with N = 5 burns)

A	AA	AC	AL	B0	B2	B4	B5
B6	B9	BC	BE	BF	C1	C2	D1
D	DX	F1	FA	FC	FD	FI	FS
H	I1	IS	K0	K2	K5	K6	K7
K9	K	KE	LA	LA(FT)	LB	LC	LP
LX	M1	M2	MF	MU	N	NA	ND
P	PC	PJ	PK	PL	PW	R1	SM
T1	T	TA	TE	TP	TQ	TR	TS
TT	TW	TX	V	W1	WA	WB	WC
WW	WX	WW	WY	WZ			

53.766	.0677651	170041	5.51664E-04	1.41088	.0537852	0	0
0	0	0	1.41088	.0332164	10	6.8	2
.0109921	2.1	7.82013E-04	7.21306	14.4261	258.821	-1.57041	.640355
93.1227	15700	425.345	2	0	0	0	0
0	19.8316	0	2020	168.333	501.475	255.478	182.525
3965.04	67611.4	30413.7	5.18641E-05	.88	5	0	.132045
726.046	9579.13	326.599	9579.13	502.301	42805.4	700	229.781
.05	0	2E-03	4.58997E-04	2.86577E-03	39.4133	10	29.4133
171.946	.01	.055	16719.8	3.53547E-04	.332116	670.873	3747.9
3578.41	40642.5	11357.6	11406.8	5837.09			

53.766	.121698	.238918	4.06749E-04	1.00497	.0065919	0	0
0	0	0	1.00497	.0285219	10	6.8	2
8.81627E-03	2.1	7.49788E-04	48.397	96.794	964.909	-1.57042	.695676
93.1227	15700	450.101	2	0	0	0	0
0	12.7575	0	2340	195	504.107	295.949	179.893
3985.85	410400	221931	3.00401E-04	.87	5	0	.428911
4407.18	9579.13	2383.21	9579.13	389.801	39881.2	700	742.354
.05	0	2E-03	4.58997E-04	.0167657	14.9568	10	4.95683
1005.94	.05	.055	15579.7	3.53547E-04	.332116	777.15	5029.42
4461.23	45840.5	14159.5	14159.7	5959.26			

53.766	.149913	.257650	3.83039E-04	1.02349	.118906	0	0
0	0	0	1.02349	.0276701	10	6.8	2
8.33105E-03	2.1	7.40496E-04	93.9446	187.889	1518.04	-1.57042	.711359
93.1227	15700	457.517	2	0	0	0	0
0	11.3918	0	2430	202.5	504.763	307.232	179.237
3991.04	779425	440552	5.61519E-04	.87	5	0	.651367
8369.88	9579.13	4730.88	9579.13	379.199	39152.5	700	1127.91
.05	0	2E-03	4.58997E-04	.0312712	12.652	10	2.65198
1876.27	.09	.055	15321.8	3.53547E-04	.372116	807.041	5423.73
4725.11	45002.9	14997.1	15007	5850.38			

53.5184	.167581	.240965	4.49627E-04	1.20194	.133009	0	0
0	0	0	1.20194	.0299875	10.3	7.04	2.1
9.78785E-03	2.2	7.48169E-04	126.91	253.82	1832.33	-1.57042	.713499
92.6938	218207	458	2	0	0	0	0
0	15.7242	0	2350	195.833	505.094	309.128	178.906
3839.74	1.05162E+06	624182	7.8438E-04	.87	5	0	.814436
11345.1	12171.7	6733.8	12171.7	370.905	38784.5	7434	1410.77
.06	0	2E-03	4.58997E-04	.0459669	11.7891	10	1.78906
2758.02	.13	.06	15060.6	3.53547E-04	.388882	913.872	5072.49
4858.39	44579.9	15420.1	15478.2	5795.38			

53.2711	181154	224838	5.20995E-04	1.39295	143782	0	0
0	0	0	1.39295	0322799	10.6	7.28	2.2
0113453	2.3	7.48044E-04	154.852	309.704	2066.18	-1.57042	71458
92.2656	292782	458	2	0	0	0	0
0	21.1263	0	2270	189.167	505.444	310.217	178.556
3698.57	1.29485E+06	800867	9.9881E-04	87	5	0	952171
14033.9	14991.6	8680.03	14991.6	359.382	38395.2	7788	1649.84
07	0	2E-03	4.58997E-04	0612136	11.33	10	1.32997
3672.82	17	.07	14789.5	3.53547E-04	450015	1021.53	4733.01
4999.38	44132.4	15867.6	15950.4	5737.21			
53.0242	192255	211185	5.94349E-04	1.58876	152672	0	0
0	0	0	1.58876	0344775	10.9	7.52	2.3
0129375	2.4	7.48192E-04	179.672	359.345	2255.75	-1.57042	71655
91.8379	382238	458	2	0	0	0	0
0	27.4723	0	2200	183.333	505.888	312.009	178.112
3567.06	1.52939E+06	981296	1.1862E-03	87	5	0	1.07403
16653.1	18039.5	10685.1	18039.5	352.081	37902.1	8142	1561.48
08	0	2E-03	4.58997E-04	0773426	11.0391	10	1.0391
4640.55	21	08	14582.8	3.53547E-04	515514	1124.13	4445.61
5177.94	43565.7	16434.3	16454.4	5663.54			
52.7777	201164	196185	6.78261E-04	1.81217	159822	0	0
0	0	0	1.81217	036831	11.2	7.76	2.4
0147494	2.5	7.48564E-04	198.622	397.245	2389.21	-1.57042	715569
91.4109	489591	458	2	0	0	0	0
0	35.7052	0	2120	176.667	506.259	311.709	177.742
3443.19	1.72568E+06	1.14497E+06	1.36879E-03	87	5	0	1.17743
18878.3	21315.9	12525.5	21315.9	347.275	37499.8	8496	2041.13
09	0	2E-03	4.58997E-04	0937983	10.9476	10	847595
5627.3	25	09	14210.4	3.53547E-04	585381	1241.01	4128.17
5326.9	43092.9	16907.1	16975.7	5602.08			
52.5315	211243	194259	6.9446E-04	1.95473	167664	0	0
0	0	0	1.95473	0372682	11.5	8	2.5
01509	2.5	7.48853E-04	228.234	456.467	2604.99	-1.57042	729346
90.9846	552233	458	2	0	0	0	0
0	37.3742	0	2110	175.833	506.458	321.331	177.542
3325.63	1.99036E+06	1.3384E+06	1.57107E-03	87	5	0	1.29636
21875.8	22339	14710.1	22339	344.054	37268.8	985	2247.36
09	0	2E-03	4.58997E-04	109867	10.7193	10	719264
6592.05	29	09	14093.4	3.53547E-04	605031	1276.61	4059.11
5407.3	42837.7	17162.3	17188.6	5563.9			
52.0402	218074	181584	7.51923E-04	2.00839	173085	0	0
0	0	0	2.00839	0387795	12.1	8.48	2.7
0163417	2.7	7.48782E-04	242.768	485.535	2682.41	-1.57042	745625
90.1337	695655	458	2	0	0	0	0
0	43.8319	0	2040	170	506.412	332.42	177.588
3107.76	2.12654E+06	1.458E+06	1.72846E-03	87	5	0	1.38198
23593.2	24389.6	16176	24389.6	341.922	37319.5	9558	2396.76
09	0	2E-03	4.58997E-04	124743	10.6344	10	634354
7484.57	33	09	14083.5	3.53547E-04	644333	1314.13	3822.43
5388.94	42896	17104	17208.5	5576.48			

51.5503	224308	171060	8.07342E-04	2.15635	178033	0	0
0	0	0	2.15635	.0401031	12.7	8.96	2.9
.0175451	2.9	7.40005E-04	256.418	512.836	2752.08	-1.57042	.762745
89.2852	.861979	458	2	0	0	0	0
0	50.5247	0	1980	165	506.428	344.145	177.572
2913.67	2.26257E+06	1.57925E+06	1.80097E-03	.87	5	0	1.46254
25340.9	26445.3	17687.7	26445.3	340.184	37302.5	1.0266	2536.92
.09	0	2E-03	4.58997E-04	.139968	10.5651	10	.565095
8398.08	37	.09	14073.4	3.53547E-04	.68363	1353.59	3600.95
5395.1	42876.4	17123.6	17228.5	5573.94			

51.306	230938	165915	8.36179E-04	2.23337	.183296	0	0
0	0	0	2.23337	.0408945	13	9.2	3
.0181718	3.1	7.40003E-04	275.594	551.188	2871.96	-1.57042	.77082
88.8619	.954259	458	2	0	0	0	0
0	54.1992	0	1950	162.5	506.426	349.667	177.574
2824.2	2.42667E+06	1.71845E+06	2.05274E-03	.97	5	0	1.55077
27420.9	27474.7	19338.4	27474.7	338.882	37304.3	1.962	2690.46
.09	0	2E-03	4.58997E-04	.155087	10.51	10	.51003
9305.22	41	.09	14063.3	3.53547E-04	.70328	1371.4	3492.65
5294.43	42878.5	17121.5	17248.1	5574.21			

APPENDIX 9-4. SPACE BASED RADAR-A ANALYSIS (Continuation of Appendix 9-2 - with N = 2 burns)

A	AA	AC	AL	B0	B2	B4	B5
B6	B9	BC	BE	BF	C1	C2	D1
D	DA	F1	FA	FC	FD	FI	FS
H	I1	IS	K0	K2	K5	K6	K7
K9	K	KE	LA	LA(FT)	LB	LC	LP
LX	M1	M2	MF	MU	N	NA	ND
P	PC	PJ	PK	PL	PN	R1	SH
T1	T	TA	TE	TP	TQ	TR	TS
TT	TW	TX	V	W1	WA	WB	WC
WH	WX	WW	WY	WZ			

53.766	0656893	147725	6.54047E-04	1.64762	0521377	0	0
0	0	0	1.64762	0361676	10	6.8	2
0126439	2.1	7.93928E-04	5.98484	11.9697	221.549	-1.5704	608757
93.1227	.15700	424.767	2	0	0	0	0
0	26.2396	0	1840	153.333	500.322	232.712	193.678
3955.93	54601	23993	4.72425E-05	.88	2	0	124827
586.334	9579.13	257.649	9579.13	449.36	44086.1	.709	215.91
05	0	2E-03	4.58997E-04	2.65231E-03	37.6869	5	32.6869
159.139	.01	055	17791.3	3.53547E-04	.332116	611.093	3109.72
3119.85	50097.9	9902.13	9913.74	6011.74			

53.766	118494	203575	4.91099E-04	1.26593	.0940489	0	0
0	0	0	1.26593	.0313401	10	6.8	2
9.94095E-03	2.1	7.75868E-04	41.2377	82.4754	844.539	-1.57041	664861
93.1227	15700	448.403	2	0	0	0	0
0	16.22	0	2160	180	502.419	273.184	181.581
3972.51	337018	180537	2.77293E-04	88	2	0	406591
3619.08	9579.13	1938.7	9579.13	298.613	41756.3	700	703.688
05	0	2E-03	4.58997E-04	0152031	10.7017	5	5.70172
912.184	05	055	16943.9	3.53547E-04	332116	717.37	4285.42
3953.99	47450.4	12549.6	12583.6	5694.05			

53.766	146977	228817	4.4577E-04	1.15437	116655	0	0
0	0	0	1.15437	0298587	10	6.8	2
9.10658E-03	2.1	7.72317E-04	93.4315	166.863	1375.34	-1.57041	687562
93.1227	15700	457.066	2	0	0	0	0
0	13.6115	0	2290	190.833	503.333	289.626	189.667
3979.73	671478	377773	5.29168E-04	98	2	0	526045
7210.69	9579.13	4056.73	9579.13	230.403	40740.8	700	1064
05	0	2E-03	4.58997E-04	0269588	7.39418	5	2.39418
1733.33	09	055	16533.3	3.53547E-04	332116	760.544	4616.79
4317.58	46296.4	13703.6	13735.9	5555.57			

53.5184	165658	224838	4.60683E-04	1.1929	131483	0	0
0	0	0	1.1929	0303514	10.3	7.04	2.1
9.41152E-03	2.1	7.72238E-04	118.416	236.833	1729.79	-1.57041	700646
92.6939	181839	458	2	0	0	0	0
0	14.5383	0	2270	189.167	503.362	298.604	180.638
3826.58	933520	540763	7.57679E-04	88	2	0	795792
10071	10143.1	5833.86	10143.1	207.334	40708.6	7434	1378.42
05	0	2E-03	4.58997E-04	041798	7.06511	5	2.06511
2507.88	13	055	16146.1	3.53547E-04	343032	778.683	4733.01
4329.11	46259.8	13740.2	14401.1	5551.17			

53.0242	179543	213109	5.12344E-04	1.36806	142504	0	0
0	0	0	1.36806	0320107	10.9	7.52	2.3
0111282	2.4	7.49005E-04	146.774	293.549	1976.21	-1.57042	72073
91.8379	.206678	458	2	0	0	0	0
0	20.3258	0	2210	184.167	504.447	313.427	179.553
3556.9	1.18155E+06	719925	9.64621E-04	87	2	0	935261
12865.7	13529.6	7839.08	13529.6	191.701	39503	.8142	1620.48
06	0	2E-03	4.58997E-04	.050075	6.44229	5	1.44229
3484.5	.17	.06	15657.8	3.53547E-04	415082	917.331	4486.11
4598.2	45405.7	14594.3	14671.7	5902.74			
52.7777	191476	205464	5.76976E-04	1.54241	151975	0	0
0	0	0	1.54241	0339699	11.2	7.76	2.4
.0125608	2.5	7.48149E-04	174.806	349.611	2204.67	-1.57042	727975
91.4109	300007	458	2	0	0	0	0
0	25.8957	0	2170	180.833	505.124	319.059	178.876
3435.47	1.44296E+06	914121	1.17062E-03	87	2	0	1.06421
15785.5	16579	10000.1	16579	183.23	38750.7	8496	1944.41
07	0	2E-03	4.58997E-04	0743727	6.10479	5	1.10479
4462.26	21	07	15166.9	3.53547E-04	480591	1042.86	4125.19
4870.64	44541	15459	15484.2	5790.33			
52.5315	20168	197960	6.44341E-04	1.72248	160072	0	0
0	0	0	1.72248	.0358982	11.5	8	2.5
0140271	2.6	7.48156E-04	200.501	401.001	2398.99	-1.57042	.734714
90.9846	490874	458	2	0	0	0	0
0	32.2944	0	2130	177.5	505.833	324.377	178.167
3321.52	1.705E+06	1.11848E+06	1.36721E-03	.87	2	0	1.18115
18739.4	19856.9	12293.1	19856.9	177.505	37963.7	855	2047.59
08	0	2E-03	4.58997E-04	0918179	5.8767	5	876703
5509.08	25	08	14645.5	3.53547E-04	550447	1172.45	4167.21
5155.65	43636.4	16363.6	16380.7	5672.74			
52.2857	.208881	181584	7.40629E-04	1.97918	165789	0	0
0	0	0	1.97918	.0384871	11.8	8.24	2.6
0161119	2.7	7.48418E-04	213.341	426.683	2463.08	-1.57042	720055
90.5598	621187	458	2	0	0	0	0
0	42.6077	0	2040	170	506.139	321.495	177.963
3211.62	1.85596E+06	1.25756E+06	1.51895E-03	87	2	0	1.26739
20494.6	23363.6	13886.6	23363.6	174.016	37625	9204	2197.5
09	0	2E-03	4.58997E-04	108146	5.7377	5	.737698
6488.75	29	09	14391.9	3.53547E-04	62468	1274.35	3822.49
5278.3	43247.1	16752.9	16827.3	5622.13			
52.2857	218074	181584	7.40629E-04	1.97918	173095	0	0
0	0	0	1.97918	.0384871	11.8	8.24	2.6
0161119	2.7	7.48418E-04	242.768	485.535	2682.41	-1.57042	730055
90.5588	621187	458	2	0	0	0	0
0	42.6077	0	2040	170	506.138	321.495	177.963
3211.62	2.10065E+06	1.43101E+06	1.72846E-03	87	2	0	1.28198
23197	23363.6	15802	23363.6	171.772	37625	9204	2396.76
09	0	2E-03	4.58997E-04	122063	5.64828	5	64828
7283.75	33	09	14376.9	3.53547E-04	62466	1274.35	3822.49
5278.3	43247.1	16752.9	16855.8	5622.13			

52.0402	.222019	160650	8.67267E-04	2.31752	.176216	0	0
0	0	0	2.31752	.0416477	12.1	8.48	2.7
.0188656	2.8	7.48443E-04	241.113	482.226	2615.82	-1.57042	.717407
90.1337	.77295	458	2	0	0	0	0
0	58.4164	0	1920	160	586.16	312.866	177.041
3106.21	2.13017E+06	1.4951E+06	1.82397E-03	.87	2	0	1.43269
23633.4	27099.6	16587.6	27099.6	169.987	37600.6	.9558	2484.98
1	0	2E-03	4.58997E-04	.13813	5.57719	5	.57719
8287.79	37	.1	14361.9	3.53547E-04	.70328	1350.3	3386.01
5287.15	43219.1	16780.9	16884.2	5618.48			
52.0402	.239146	162530	8.60782E-04	2.29986	.182667	0	0
0	0	0	2.29986	.0414917	12.1	8.48	2.7
.0187191	2.8	7.49551E-04	269.97	539.94	2823.25	-1.57042	.71966
90.1337	.77295	458	2	0	0	0	0
0	57.513	0	1930	160.833	506.248	314.495	177.752
3106.75	2.38066E+06	1.67715E+06	2.03169E-03	.87	2	0	1.54009
26412.6	27099.6	16607.4	27099.6	168.483	37502.1	.9558	2671.87
1	0	2E-03	4.58997E-04	.153726	5.51724	5	.517229
9224.15	41	.1	14346.3	3.53547E-04	.70328	1257.33	3421.38
5222.82	43105.8	16894.2	16913.3	5603.76			

APPENDIX 9-5. SPACE BASED RADAR-A ANALYSIS (Baseline with Construction Material Changed to Aluminum)

OPTOTV/OOA - 1 PAYLOAD, 1 OTV, 1 SHUTTLE

B1	B	BP	CD	D2	DD	DM	DT
DV	E	EE	EM	FB	G	K1	KP
KQ	KS	KT	LD	LM	LQ	MH	MV
PI	RH	RM	RS	S1	SP	T2	T0
TD	TF	TG	TM	TN	TY	T2	WL
WS	WT						

100	1	1	014	1	1	2	2
01	1.01E+07	.107	200000	3.218	22.17	.2	21
5	15	4.1	10	1000	684	6	85
3.14159	.090	.0513	80	35000	3370	.025	2E-03
5E-03	.04	9E-03	.05	.01	41	.02	3.3E-04
60000	1						

A	AA	AC	AL	B0	B2	B4	B5
B6	B9	BC	BE	BF	C1	C2	D1
D	DX	F1	FA	FC	FD	FI	FS
H	I1	IS	K0	K2	K5	K6	K7
K9	K	KE	LA	LA(FT)	LB	LC	LP
LX	M1	M2	MF	MU	N	NA	ND
P	PC	PJ	PK	PL	PW	R1	SM
T1	T	TA	TE	TP	T0	TP	TS
TT	TW	TX	V	W1	WA	WB	WC
WH	WX	WW	WY	WZ			

53.766	066512	159178	2.76801E-04	738823	0527906	0	0
0	0	0	738823	.0235287	10	6.8	2
6.00744E-03	2.1	7.49301E-04	6.44887	12.8977	275.768	-1.57042	617482
93.1227	15700	426.201	2	0	0	0	0
0	5.92243	0	1910	159.167	503.208	241.566	180.792
3978.74	66182.5	33104.7	4.90390E-05	88	9	0	127975
710.703	5416.59	355.495	9061.34	612.442	40600.5	708	221.256
05	0	2E-03	4.58997E-04	3.18659E-03	50.3134	25	25.3134
191.195	01	055	15267.7	3.53547E-04	516624	966.752	3250.93
4267.58	46455.1	13544.9	13596.1	6006.72			

53.766	118311	201694	2.1361E-04	593982	.0939035	0	0
0	0	0	.593982	.0206693	10	6.8	2
5.03016E-03	2.1	7.19346E-04	40.8567	81.7135	838.04	-1.57044	658509
93.1227	.15700	451.337	2	0	0	0	0
0	4.15297	0	2150	179.167	505.499	271.919	178.501
3996.86	379858	221042	2.76099E-04	87	9	0	405333
4036.16	5416.59	2273.67	9061.24	516.400	38334.1	.708	701.51
05	0	2E-03	4.58997E-04	.0100549	29.4365	25	4.43648
1083.29	05	055	14455.3	3.53547E-04	516624	1110.74	4245.83
5021.49	44062.2	15937.8	16001.6	6300.08			

53.5184	.141651	.183369	2.55285E-04	.711245	.112429	0	0
0	0	0	.711245	.0225958	10.3	7.04	2.1
6.03655E-03	2.2	7.17853E-04	66.8601	133.72	1143.97	-1.57044	.65456
92.6938	.218207	457.754	2	0	0	0	0
0	5.90098	0	2050	170.833	505.946	269.664	178.054
3846.22	612765	387412	4.73705E-04	.87	9	0	.501400
6610.64	7594.24	4179.40	11513.7	507.006	37830.3	.7434	1096.62
.06	0	2E-03	4.58997E-04	.0332426	27.4122	25	2.41221
1994.56	.09	.06	14370.9	3.53547E-04	.604927	1240.1	3868.06
5201.06	43492.3	16507.7	16517.6	6330.13			
53.2711	.156392	.159170	3.12156E-04	.869992	.124128	0	0
0	0	0	.869992	.0249862	10.6	7.28	2.2
7.38642E-03	2.3	7.17606E-04	83.8353	167.671	1298.01	-1.57044	.6418
92.2656	.292702	458	2	0	0	0	0
0	8.95494	0	1910	159.167	506.028	261.02	177.972
3702.84	776391	517338	6.37518E-04	.87	9	0	.709036
8414.75	10281.7	5607.06	14181.2	503.636	37746.3	.7708	1227.92
.07	0	2E-03	4.58997E-04	.0482164	26.6599	25	1.65993
2892.98	.13	.07	14287.7	3.53547E-04	.700023	1237.04	3350.83
5224.38	47386.5	16613.5	16681.9	6320.72			
53.0242	.170422	.155862	3.2241E-04	.899042	.135264	0	0
0	0	0	.899042	.0253933	10.9	7.52	2.3
7.63706E-03	2.3	7.17231E-04	107.347	214.694	1523.73	-1.57044	.651876
91.8379	.334458	458	2	0	0	0	0
0	9.57299	0	1890	157.5	506.161	268.044	177.839
3568.38	990452	674387	8.24947E-04	.87	9	0	.842265
10794.8	11858.1	7343.23	14931.4	501.778	37599.2	.8142	1459.24
.07	0	2E-03	4.58997E-04	.0634689	26.2561	25	1.25611
3000.14	.17	.07	14203	3.53547E-04	.723797	1367.98	3291.02
5287.65	43217.5	16782.5	16824.6	6305.67			
52.7777	.182212	.152581	3.32772E-04	.928373	.144621	0	0
0	0	0	.928373	.0257981	11.2	7.76	2.4
7.98994E-03	2.5	7.16892E-04	129.813	259.627	1721.89	-1.57044	.661787
91.4109	.380007	458	2	0	0	0	0
0	10.2174	0	1870	155.833	506.287	274.95	177.713
3443.38	1.19783E+06	829995	1.00827E-03	.87	9	0	.963263
12103.8	12599.2	9072.93	15682.8	500.631	37458.4	.8496	1669.27
.07	0	2E-03	4.58997E-04	.0788955	26.0067	25	1.03672
4733.73	.21	.07	14117.2	3.53547E-04	.747571	1397.96	3211.96
5338.62	43855.7	16944.3	16989.2	6291.26			
52.5315	.192424	.149335	3.43256E-04	.958027	.152727	0	0
0	0	0	.958027	.0262014	11.5	8	2.5
8.14541E-03	2.5	7.16509E-04	151.252	302.503	1898.24	-1.57044	.671531
90.9946	.429515	458	2	0	0	0	0
0	10.8898	0	1850	154.167	506.400	281.736	177.592
3325.3	1.39894E+06	993920	1.18748E-03	.87	9	0	1.07401
15375.6	15515.3	10814.1	16435.6	499.653	37324	.885	1962.83
.07	0	2E-03	4.58997E-04	.0944833	25.8376	25	.837616
5669	.25	.07	14038.6	3.53547E-04	.771345	1426.99	3145.62
5387.31	42901.2	17090.9	17145.9	6277.5			

52.0402	.192974	139905	3.71208E-04	1.03617	.158719	0	0
0	0	0	1.03617	.0272473	12.1	8.48	2.7
8.81093E-03	2.7	7.16499E-04	164.256	328.512	1982.37	-1.57044	.666019
90.1337	.541063	458	2	0	0	0	0
0	12.742	0	1750	149.167	506.445	291.682	177.555
3107.96	1.53461E+06	1.10134E+06	1.3328E-03	.87	9	0	1.16116
17825.9	17944.3	12218.9	17944.3	499.312	37282.9	.9558	2012.96
.07	0	2E-03	4.58997E-04	.109799	25.72	25	.715981
6587.97	.29	.07	13994.6	3.53547E-04	.818893	1465.82	2943.01
5402.2	42853.9	17146.1	17211.7	6273.29			

51.5503	.206415	130590	4.01072E-04	1.11955	.163832	0	0
0	0	0	1.11955	.0283221	12.7	8.96	2.9
9.52011E-03	2.9	7.16486E-04	174.591	349.183	2048.22	-1.57044	.699184
89.2652	.670428	458	2	0	0	0	0
0	14.8758	0	1720	144.167	506.451	209.692	177.549
2913.81	1.64926E+06	1.20553E+06	1.4658E-03	.87	9	0	1.23752
18471.8	19456.7	12502	19456.7	498.909	37276.8	1.9266	2145.57
.07	0	2E-03	4.58997E-04	.124977	25.6324	25	.67244
7498.65	.33	.07	13986.1	3.53547E-04	.566441	1448.94	2749.02
5404.39	42846.9	17153.1	17227.4	6272.67			

51.306	.213193	126100	4.16814E-04	1.16346	.169211	0	0
0	0	0	1.16346	.0298726	12	9.2	3
[illegible]	3.1	7.16500E-04	189.024	378.047	2137.35	-1.57044	.705259
98.9619	.742202	458	2	0	0	0	0
0	16.0644	0	1700	141.667	506.442	304.838	177.558
2824.29	1.79219E+06	1.32407E+06	1.61490E-03	.87	9	0	1.22051
20168.2	20214.1	14900.3	20214.1	498.597	37287	1.062	2289.96
.07	0	2E-03	4.58997E-04	.140064	25.5645	25	.564473
9403.82	.37	.07	13977.7	3.53547E-04	.898214	1513.36	2654.51
5400.72	42858.6	17141.4	17242.9	6273.71			

51.0619	.214384	106186	5.12672E-04	1.43125	.170156	0	0
0	0	0	1.43125	.0320821	13.3	9.44	3.1
.0121722	3.2	7.16397E-04	176.38	352.76	1983.1	-1.57044	.681161
88.4392	.935912	458	2	0	0	0	0
0	24.3181	0	1560	130	506.469	288.403	177.511
2729.65	1.74992E+06	1.33583E+06	1.64219E-03	.87	9	0	1.27538
19786.7	23968.2	15104.5	23968.2	499.335	37234.9	1.0274	2215.72
.08	0	2E-03	4.58997E-04	.155562	25.5975	25	.587528
9733.69	.41	.08	13969.1	3.53547E-04	1.01927	1590.07	2215.3
5419.58	42798.7	17201.3	17250.7	6268.38			

APPENDIX 9-6. SPACE BASED RADAR-A ANALYSIS (Baseline with Truss End Weight WT Changed to 1000 Pounds)

OPTOTV/OOA - 1 PAYLOAD, 1 OTV, 1 SHUTTLE

B1	B	BP	CD	D2	DD	DM	DT
DV	E	EE	EM	FB	G	K1	LD
LM	LQ	MH	MV	PI	RH	RM	RS
S1	SP	T2	T0	TD	TF	TG	TM
TN	TY	TZ	WL	WS	WT		

100	1	1	.014	1	.5	2	3
.01	4E+07	.107	300000	3.218	32.17	.2	40
300	684	.6	.85	3.14159	.063	.0513	88
37000	3330	.025	2E-03	.01	.94	9E-03	.05
.01	.41	.02	3.3E-04	60000	1000		

A	AA	AC	AL	B0	B2	B4	B5
B6	B9	BC	BE	BF	C1	C2	D1
D	DX	F1	FA	FC	FD	FI	FS
H	I1	IS	K0	K2	K5	K6	K7
K9	K	KE	LA	LA(FT)	LB	LC	LP
LX	M1	M2	MF	MU	N	NA	ND
P	PC	PJ	PK	PW	R1	SM	T1
T	TA	TE	TP	TT	TW	TX	V
W1	WA	WB	WC	WH	WX	WW	WY
WZ							

53.766	.0560003	56785.8	.0376414	3.18266	.0444475	0	0
0	0	0	3.18288	.274377	10	6.8	2
.819881	2.5	.0236529	2.29735	4.59469	99.7826	-1.55897	.474789
93.1227	.15708	426.308	2	0	0	0	0
0	110.331	0	1140	95	503.425	144.18	180.575
3980.46	41945.5	30136.8	2.92698E-05	.88	9	0	.0907083
450.433	9579.13	323.625	9579.13	40638.9	.708	156.884	.05
0	2E-03	4.58997E-04	3.22685E-03	193.611	.01	.06	15263.2
3.53547E-04	.332116	378.612	1193.7	4354.07	46180.6	13819.4	14222.2
6064.16							

53.766	.105857	103491	.0220962	1.94606	.0040187	0	0
0	0	0	1.94619	.21022	10	6.8	2
.522188	2.5	.0227076	20.9618	41.9236	400.829	-1.55944	.545165
93.1227	.15708	451.648	2	0	0	0	9
0	44.7558	0	1540	128.333	505.877	194.77	178.123
3999.85	304163	230636	1.977E-04	.87	9	0	.324394
3266.26	9579.13	2476.7	9579.13	37913.9	.708	561.332	.05
0	2E-03	4.58997E-04	.0184051	1104.3	.05	.06	14453.3
3.53547E-04	.332116	511.458	2178.35	5173.66	43579.2	16420.8	16538.9
6337.88							

53.766	.130961	114511	.0204076	1.80052	.103944	0	0
0	0	0	1.80064	.202028	10	6.8	2
.483989	2.5	.0226675	41.7531	83.5063	773.189	-1.55946	.559303
93.1227	.15700	457.800	2	0	0	0	0
0	38.4473	0	[illegible]	135	506.325	204.888	177.675
4003.39	579646	448111	[illegible]	.87	9	0	.496000
6224.54	9579.13	4812.05	[illegible]	37416.5	.700	859.993	.05
0	2E-03	4.58997E-04	.0338752	2032.51	.09	.06	14367.4
3.53547E-04	.372116	530.027	2410.55	5252.01	43007.5	16992.5	17033.9
6286.97							
53.766	.140039	114511	.0204076	1.80052	.117498	0	0
6	0	0	1.80064	.202028	10	6.8	2
.483989	2.5	.0226675	60.3101	120.62	986.996	-1.55946	.559303
93.1227	.15700	458	2	0	0	0	0
0	38.4473	0	1620	135	506.325	204.888	177.675
4003.39	824786	647272	5.40722E-04	.87	9	0	.635146
8856.99	9579.13	6950.74	9579.13	37416.5	.700	1099.78	.05
0	2E-03	4.58997E-04	.0489309	2499	.13	.06	14283.7
3.53547E-04	.332116	538.027	2410.55	5353.01	43007.5	16992.5	17192.6
6286.97							
52.5315	.159176	103481	.0240307	2.12112	.126338	0	0
0	0	0	2.12125	.219229	11.5	8	2.5
.57042	2.5	.0226575	71.2701	142.54	1003.96	-1.55947	.602444
90.9846	.306796	458	2	0	0	0	0
0	53.4053	0	1540	128.333	506.454	234.526	177.546
3325.6	1.00003E+06	806170	6.72179E-04	.87	9	0	.734576
11000.7	12410.5	8860.52	12410.5	37273.3	.805	1272.22	.05
0	2E-03	4.58997E-04	.0643923	2499	.17	.06	14197.8
3.53547E-04	.386698	595.516	2178.35	5405.66	42842.9	17157.1	17345.5
6272.31							
51.306	.167782	93000.6	.027037	2.45775	.133169	0	0
0	0	0	2.45791	.235954	13	9.2	3
.661127	3.5	.0226514	79.1301	158.26	1141.1	-1.55947	.642201
88.8619	.530144	458	2	0	0	0	0
0	71.7406	0	1460	121.667	506.536	261.802	177.464
2824.82	1.14662E+06	944049	7.87205E-04	.87	9	0	.816395
12903.4	15263.7	10623.8	15263.7	37181.8	1.062	1414.17	.05
0	2E-03	4.58997E-04	.0790639	2499	.21	.06	14111.9
3.53547E-04	.441282	644.271	1957.91	5438.82	42737.6	17262.4	17499.5
6262.94							
50.0893	.176183	87982	.0305513	2.6997	.139837	0	0
0	0	0	2.69987	.247189	14.5	10.4	3.5
.72683	3.5	.0226321	89.1114	178.223	1223.01	-1.55948	.690069
86.7547	.841849	458	2	0	0	0	0
0	86.7082	0	1420	118.333	506.826	294.833	177.174
2441.02	1.32281E+06	1.10598E+06	9.11473E-04	.87	9	0	.900471
15247.7	18130.3	12748.3	18130.3	36860	1.239	1560.09	.05
0	2E-03	4.58997E-04	.0964168	2499	.25	.06	14019.9
3.53547E-04	.495864	704.128	1852.09	5555.35	42367.8	17632.2	17665.1
6230.01							

50.0893	.185119	87902	.0305513	2.6997	.146929	0	0
0	0	0	2.69987	.247189	14.5	10.4	3.5
.72683	3.5	.0226321	103.369	206.738	1349.29	-1.55948	.690069
86.7547	.841849	458	2	0	0	0	0
0	86.7002	0	1420	118.333	506.826	294.833	177.174
2441.02	1.52823E+06	1.28293E+06	1.05731E-03	.87	9	0	.994464
17615.6	18130.3	14700	18130.3	36860	1.239	1723.28	.05
0	2E-03	4.58997E-04	.111843	2499	.29	.06	13993.4
3.53547E-04	.495864	704.128	1852.09	5555.35	42367.8	17632.2	17713.1
6230.01							

48.8815	.189567	78347.8	.03477	3.07248	.150459	0	0
0	0	0	3.07267	.263704	16	11.6	4
.827186	4.5	.0226322	104.747	209.493	1334.72	-1.55948	.723932
84.6628	1.25664	458	[illegible]	0	0	0	0
0	112.396	0	1340	111.667	506.824	317.993	177.176
2135.72	1.60829E+06	1.37251E+06	1.13536E-03	.87	9	0	1.04301
18996.5	21005.8	16211.5	21005.8	36862.5	1.416	1807.58	.05
0	2E-03	4.58997E-04	.127256	2499	.33	.06	13984.9
3.53547E-04	.550447	737.6	1649.28	5554.45	42370.7	17629.3	17728.6
6230.27							

47.6326	.192936	69272.1	.0394652	3.4969	.153133	0	0
0	0	0	3.48713	.280946	17.5	12.8	4.5
.938634	4.5	.0226353	103.839	207.678	1299.69	-1.55948	.753599
82.5862	1.78924	458	2	0	0	0	0
0	144.606	0	1260	105	506.775	338.237	177.225
1887.84	1.66071E+06	1.43874E+06	1.19698E-03	.87	9	0	1.09056
20103.8	23887.5	17421	23887.5	36916.6	1.593	1872.81	.05
0	2E-03	4.58997E-04	.142348	2499	.37	.06	13976.5
3.53547E-04	.605031	762.338	1458.23	5534.84	42432.9	17567.1	17743.8
6235.81							

47.6826	.199652	69272.1	.0394652	3.4869	.158464	0	0
0	0	0	3.48713	.280946	17.5	12.8	4.5
.938634	4.5	.0226353	115.065	230.129	1390.97	-1.55948	.753599
82.5862	1.78924	458	2	0	0	0	0
0	144.606	0	1260	105	506.775	328.237	177.225
1887.84	1.83603E+06	1.59428E+06	1.32639E-03	.87	9	0	1.15742
22231.7	23887.5	19304.4	23887.5	36916.6	1.593	2006.35	.05
0	2E-03	4.58997E-04	.157736	2499	.41	.06	13967.9
3.53547E-04	.605031	762.338	1458.23	5534.84	42432.9	17567.1	17759.3
6235.81							

APPENDIX 9-7. SPACE BASED RADAR-A ANALYSIS (Baseline with IS = 450 Seconds - Held Constant)

OPTOTV/OOA - 1 PAYLOAD, 1 OTV, 1 SHUTTLE

B1	B	BP	CD	D2	DD	DM	DT
DV	E	EE	EM	FB	G	K1	KP
KQ	KS	KT	LD	LM	LQ	MH	MV
PI	RH	RM	RS	S1	SP	T2	T0
TD	TF	TG	TM	TN	TV	TZ	WL
WS	WT						
100	1	1	.014	1	.5	2	3
.01	4E+07	.107	300000	3.218	32.17	.2	21
.5	15	4.1	40	100	684	.6	.85
3.14159	.063	.0513	80	37000	3330	.025	2E-03
.01	.04	9E-03	.05	.01	.41	.02	3.3E-04
60000	1						

A	AA	AC	AL	B0	B2	B4	B5
B6	B9	BC	BE	BF	C1	C2	D1
D	DX	F1	FA	FC	FD	FI	FS
H	I1	IS	K0	K2	K5	K6	K7
K9	K	KE	LA	LA(FT)	LB	LC	LP
LX	M1	M2	MF	MU	N	NA	ND
P	PC	PJ	PK	PL	PW	R1	SM
T1	T	TA	TE	TP	TQ	TR	TS
TT	TW	TX	V	W1	WA	WB	WC
WH	WX	WW	WY	WZ			

53.766	.0711696	278918	3.8136E-04	1.05056	.0564873	0	0
0	0	0	1.05056	.0276174	10	6.8	2
8.81627E-03	2.5	7.2601E-04	9.6794	19.3588	330.672	-1.57043	.695676
93.1227	.15708	450	2	0	0	0	0
0	12.7575	0	2340	195	504.107	295.949	179.893
3985.85	95316.8	44386.2	6.00002E-05	.87	9	0	.146536
1023.56	9579.13	476.643	9579.13	609.981	39881.2	.708	253.469
.05	0	2E-03	4.58997E-04	3.35313E-03	49.7706	25	24.7706
201.188	.01	.06	15248.9	3.53547E-04	.332116	777.15	5829.42
4461.23	45840.5	14159.5	14477.2	6539.22			

53.766	.124411	272707	3.39805E-04	.943684	.0987451	0	0
0	0	0	.943684	.0260693	10	6.8	2
7.9836E-03	2.5	7.20167E-04	55.2417	110.483	1077.21	-1.57044	.723539
93.1227	.15708	450	2	0	0	0	0
0	10.4615	0	2500	208.333	505.285	316.185	178.715
3995.16	483788	263518	3.20941E-04	.87	9	0	.448278
5195.17	9579.13	2829.8	9579.13	516.702	38572.7	.708	775.906
.05	0	2E-03	4.58997E-04	.0178561	29.5004	25	4.50043
1071.36	.05	.06	14456.4	3.53547E-04	.332116	830.289	5740.71
4935.06	44336.5	15663.5	15924.1	6405.3			

53.766	.152141	281504	3.30762E-04	.920025	.120755	0	0
0	0	0	.920025	.0257201	10	6.8	2
7.79575E-03	2.5	7.19029E-04	102.642	205.285	1634.05	-1.57044	.730493
93.1227	.15700	450	2	0	0	0	0
0	9.97496	0	2540	211.667	505.587	321.244	178.413
3997.56	871791	494372	5.86937E-04	.87	9	0	.670926
9361.75	9579.13	5308.83	9579.13	507.225	38236.3	.708	1161.83
.05	0	2E-03	4.58997E-04	.0326456	27.4401	25	2.44011
1958.73	.09	.06	14374.2	3.53547E-04	.332116	843.573	5925.08
5056.93	43949.8	16050.2	16078.2	6370.87			

52.5315	.169229	255534	3.88408E-04	1.08063	.134317	0	0
0	0	0	1.08063	.0278743	11.5	8	2.5
9.15699E-03	2.5	7.19002E-04	134.583	269.166	1923.97	-1.57044	.799628
90.9046	.306796	450	2	0	0	0	0
0	13.7626	0	2420	201.667	505.595	368.541	178.405
3319.96	1.12724E+06	671139	8.07745E-04	.87	9	0	.830578
12389.4	12410.5	7376.31	12410.5	503.766	38227.7	.885	1438.78
.05	0	2E-03	4.58997E-04	.0471732	26.6883	25	1.68827
2830.39	.13	.06	14293.5	3.53547E-04	.386698	935.01	5379.19
5060.02	43939.9	16060.1	16224.5	6369.99			

51.306	.181948	230820	4.48819E-04	1.24813	.144412	0	0
0	0	0	1.24813	.0299606	13	9.2	3
.0105736	3.5	7.19187E-04	158.972	317.944	2111.76	-1.57044	.863867
88.8619	.530144	450	2	0	0	0	0
0	18.3502	0	2300	191.667	505.543	412.428	178.457
2819.28	1.32289E+06	819825	1.0039E-03	.87	9	0	.960572
14887	15263.7	9225.83	15263.7	501.964	38285.4	1.062	1664.43
.05	0	2E-03	4.58997E-04	.0615246	26.2964	25	1.29641
3691.48	.17	.06	14213.8	3.53547E-04	.441282	1014.95	4858.94
5039.13	44006.3	15993.8	16368.2	6375.9			

50.0893	.192936	215042	4.98895E-04	1.38655	.153133	0	0
0	0	0	1.38655	.0315625	14.5	10.4	3.5
.0117581	3.5	7.18465E-04	182.954	365.908	2289.92	-1.57044	.93448
86.7547	.841849	450	2	0	0	0	0
0	22.6917	0	2220	185	505.752	460.937	178.248
2435.85	1.53198E+06	983183	1.19698E-03	.87	9	0	1.00056
17658.8	18130.3	11332	18130.3	500.747	38052.9	1.239	1872.81
.05	0	2E-03	4.58997E-04	.076815	26.0321	25	1.03285
4608.9	.21	.06	14128.8	3.53547E-04	.495864	1100.82	4526.8
5123.35	43738.9	16261.1	16521.5	6352.1			

48.8815	.199446	185162	5.84262E-04	1.62236	.1583	0	0
0	0	0	1.62236	.0341837	16	11.6	4
.0137233	4.5	7.20263E-04	187.539	375.078	2269.46	-1.57044	.976016
84.6628	1.25664	450	2	0	0	0	0
0	30.9111	0	2060	171.667	505.26	488.855	178.74
2129.13	1.55661E+06	1.03103E+06	1.32228E-03	.87	9	0	1.15582
18386	21085.8	12178.1	21085.8	500.148	38599.5	1.416	2082.18
.05	0	2E-03	4.58997E-04	.0891686	25.9018	25	.901839
5350.11	.25	.06	14060.2	3.53547E-04	.550447	1133.92	3897.8
4925.37	44367.3	15632.7	16645.6	6408.05			

47.6826	.201085	144531	7.40203E-04	2.03826	.159601	0	0
0	0	0	2.03826	.0384761	17.5	12.8	4.5
.017098	4.5	7.26300E-04	169.808	339.615	2037.86	-1.57043	.977348
82.5862	1.78924	450	2	0	0	0	0
0	47.9826	0	1820	151.667	504.058	488.564	179.942
1877.72	1.37476E+06	938999	1.35514E-03	.87	9	0	1.17416
16646.3	23887.5	11369.9	23887.5	499.946	39935.7	1.593	2035.44
.05	0	2E-03	4.58997E-04	.0969775	25.8579	25	.857924
5818.65	.29	.06	14016.8	3.53547E-04	.605031	1101.16	3042.49
4441.49	45903.1	14096.9	16724.1	6544.8			

47.6826	.209935	144531	7.40203E-04	2.03826	.166625	0	0
0	0	0	2.03826	.0384761	17.5	12.8	4.5
.017098	4.5	7.26300E-04	193.229	386.459	2219.47	-1.57043	.977348
82.5862	1.78924	450	2	0	0	0	0
0	47.9826	0	1820	151.667	504.058	488.564	179.942
1877.72	1.55587E+06	1.06852E+06	1.54206E-03	.87	9	0	1.28027
18839.3	23887.5	12938.2	23887.5	499.468	39935.7	1.593	2219.9
.05	0	2E-03	4.58997E-04	.110354	25.7539	25	.753933
6621.23	.33	.06	13994.2	3.53547E-04	.605031	1101.16	3042.49
4441.49	45903.1	14096.9	16765.4	6544.8			

47.6826	.218095	144531	7.40203E-04	2.03826	.173102	0	0
0	0	0	2.03826	.0384761	17.5	12.8	4.5
.017098	4.5	7.26300E-04	216.651	433.302	2393.6	-1.57043	.977348
82.5862	1.78924	450	2	0	0	0	0
0	47.9826	0	1820	151.667	504.058	488.564	179.942
1877.72	1.73634E+06	1.19003E+06	1.72897E-03	.87	9	0	1.38225
21024.5	23887.5	14506.5	23887.5	499.093	39935.7	1.593	2397.24
.05	0	2E-03	4.58997E-04	.12373	25.6724	25	.672427
7423.8	.37	.06	13986.8	3.53547E-04	.605031	1101.16	3042.49
4441.49	45903.1	14096.9	16779.3	6544.8			

47.6826	.225687	144531	7.97199E-04	2.21393	.179128	0	0
0	0	0	2.21393	.0399299	17.5	12.8	4.5
.0187299	5	7.20168E-04	240.073	480.146	2561.31	-1.57044	.975555
82.5862	2.14700	450	2	0	0	0	0
0	57.5792	0	1820	151.667	505.204	488.564	178.716
1882.29	2.04968E+06	1.46090E+06	1.91589E-03	.87	9	0	1.48069
24818.7	28665	17690.4	28665	498.525	38572.9	1.593	2568.49
.06	0	2E-03	4.58997E-04	.146418	25.5468	25	.548839
8785.11	.41	.07	13974.2	3.53547E-04	.70328	1279.97	3042.49
4935.02	44336.7	15663.3	16802.7	6405.32			

APPENDIX 10-1. SPACE BASED RADAR-R ANALYSIS (Baseline Configuration Including N = 5 and 2 Burns)

OPTOTV/OOA - 1 PAYLOAD, 1 OTV, 1 SHUTTLE
ANNULAR PHASED ARRAY

B1	B	BP	CD	D2	D8	DD	DM
DT	DV	E	EE	EM	FB	G	GE
K1	KP	KQ	KS	KT	LD	LF	LM
LQ	MH	MV	PI	RH	RM	RS	S1
SP	T2	T0	TD	TF	TG	TL	TM
TN	TY	TZ	WL	WN	WS	WT	WU
ZH							

100	1	1	.014	1	36	.1	2
3	.01	4E+07	.107	300000	1	32.17	3.54E+06
.2	21	.5	15	4.1	10	40	1700
684	.6	.85	3.14159	.063	.0513	80	37000
3330	.025	2E-03	5E-03	.04	9E-03	.125	.05
.01	.41	.02	3.3E-04	10	60000	1	10502
.47							

A1	A	AA	AC	AL	AM	AT	B0
B2	B4	B5	B6	B9	BC	BE	BF
BU	C1	C2	D1	D	DA	DX	F1
FA	FC	FD	FI	FS	H	I1	I
IS	K0	K2	K5	K6	K7	K9	K
KE	LA	LA(FT)	LB	LC	LP	LX	M1
M2	MF	MU	N	NA	ND	NO	P
PC	PJ	PK	PL	PW	R1	SM	T1
T	TA	TE	TP	TQ	TR	TS	TT
TW	TX	V	W1	W	WA	WB	WC
WH	WP	WX	WW	WY	WZ	XB	ZI

.392699	300	0	253426	2.57794E-03	7.74735E-03	1.1781	6.67306
0	0	0	0	0	0	6.67305	.0718044
.0291802	11.5	8	2.5	.0526201	134.305	2.5	7.72641E-04
0	0	0	-1.57041	.761373	519.6	.306796	17670.4
426.208	2	0	0	0	0	0	454.463
0	2410	200.833	463.221	0	100.779	2587.8	210688
0	0	.88	9	0	0	50.4749	1216.45
1345.76	0	12410.5	612.309	40065.4	.005	233.272	.05
0	2E-03	4.58997E-04	3.18911E-03	50.2845	25	25.2845	191.346
.01	.055	15267.4	3.53547E-04	.107071	.18325	2774.86	6451.05
4336.18	.1	46437.9	13562.1	13597.1	5572.55	86.6	0
.934624	300	0	247156	3.00125E-03	7.94389E-03	2.00387	10.1596
0	0	0	0	0	0	10.1596	.0071923
.0299205	14.5	10.4	3.5	.0827181	125.075	3.6	7.48308E-04
0	0	0	-1.57042	.750879	519.6	1.4[illegible]114	42855.6
450.846	2	0	0	0	0	0	1123.04
0	2300	198.333	464.927	0	179.074	2395.64	1.01471E+06
0	0	.87	9	0	0	49.8466	5650.58
6277.7	0	30821.6	517.351	38970.6	1.239	1151.84	.005
0	2E-03	4.58997E-04	.0175245	29.6416	25	4.64157	1051.47
05	09	14458.2	3.53547E-04	.520693	.271027	4052.94	6291.44
51.86	.1	44793.8	15206.2	15967.9	5823.19	86.6	0

1.39407	300	0	238918	4.76174E-03	8.21779E-03	4.1046	12.7289
0	0	0	0	0	0	12.7289	.0975083
.0309521	15.1	10.88	3.7	.103655	123.229	3.8	7.40179E-04
0	0	0	-1.57042	.757503	519.6	2.30697	62765.3
457.742	2	0	0	0	0	0	1763.5
0	2340	195	465.868	0	178.132	2357.07	1.7362E+06
0	0	.87	9	0	0	49.0008	10024.2
10470.4	0	46271.1	507.164	37924.1	1.3090	2038.47	.12
0	2E-03	4.58997E-04	.0331138	27.427	25	2.42702	1986.03
.09	.125	14371.6	3.53547E-04	.935653	.345574	5000.06	6081.75
5246.43	.1	43591	16409	16515.5	5666.03	86.6	0

1.63363	300	0	226023	5.35943E-03	8.65599E-03	4.90008	14.3246
0	0	0	0	0	0	14.3246	.103532
.0326026	16	11.6	4	.116633	120.46	4	7.40283E-04
0	0	0	-1.57042	.757308	519.6	3.26726	73500.9
458	2	0	0	0	0	0	2232.74
0	2280	130	466.002	0	177.998	2299.1	2.32042E+06
0	0	.87	9	0	0	47.7522	13397.3
14331.8	0	54615.2	503.652	37776	1.416	2868.96	.13
0	2E-03	4.58997E-04	.048152	26.6635	25	1.66346	2809.12
.13	.135	14288	3.53547E-04	1.31685	.384247	5504.6	5773.86
5300.08	.1	43420.7	16579.3	16681.2	5644.69	86.6	0

1.78128	300	0	220093	5.7107E-03	8.88837E-03	5.34385	15.2608
0	0	0	0	0	0	15.2608	.106871
.0334778	16.6	12.08	4.2	.124234	118.614	4.2	7.40414E-04
0	0	0	-1.57042	.757115	519.6	3.92773	80153
458	2	0	0	0	0	0	2533.23
0	2250	187.5	466.134	0	177.866	2260.38	2.91658E+06
0	0	.87	9	0	0	47.1239	16839.4
17229	0	59826.3	501.79	37629.3	1.4868	3702.35	.135
0	2E-03	4.58997E-04	.0633838	26.2508	25	1.25081	3903.03
.17	.14	14203.4	3.53547E-04	1.69937	.408163	5770.27	5622.91
5354.8	.1	43252	16748	16833.7	5622.76	86.6	0

1.93522	300	0	213109	6.11565E-03	9.21303E-03	5.80566	16.3417
0	0	0	0	0	0	16.3417	.110595
.0347007	17.2	12.56	4.4	.133022	116.768	4.4	7.40474E-04
0	0	0	-1.57042	.757038	519.6	4.68324	87079.8
458	2	0	0	0	0	0	2904.31
0	2210	184.167	466.186	0	177.814	2221.6	3.41471E+06
0	0	.87	9	0	0	46.2061	19715.4
20543	0	65270.2	500.668	37571.1	1.5576	4492.19	.14
0	2E-03	4.58997E-04	.0785013	26.0148	25	1.01402	4710.08
.21	.145	14119.4	3.53547E-04	2.0619	.433097	6013.92	5424.77
5376.18	.1	43185.1	16814.9	16985.2	5614.07	86.6	0

2.09544	300	0	205464	6.54179E-03	9.55502E-03	6.28633	17.4787
0	0	0	0	0	0	17.4787	.114384
.0359918	17.8	13.04	4.6	.142264	114.922	4.6	7.40545E-04
0	0	0	-1.57042	.756953	519.6	5.54245	94209.3
458	2	0	0	0	0	0	3321.9
0	2170	180.833	466.244	0	177.756	2182.75	3.84913E+06
0	0	.87	9	0	0	45.4404	22223.6
24311.9	0	70946.9	499.903	37506.6	1.6204	5251.05	.145
0	2E-03	4.58997E-04	.0937224	25.8485	25	.840540	5623.34
.25	.15	14034.9	3.53547E-04	2.41022	.459049	6258.91	5230.17
5399.06	.1	43111.1	16888.9	17138.2	5604.44	86.6	0

2.141	300	0	201694	6.70364E-03	9.73443E-03	6.42299	17.9129
0	0	0	0	0	0	17.9129	.11579
.0366645	18.1	13.28	4.7	.145814	113.999	4.8	7.40469E-04
0	0	0	-1.57042	.757044	519.6	5.91182	96339.1
450	2	0	0	0	0	0	3489.72
0	2150	179.167	466.182	0	177.818	2163.31	4.34311E+06
0	0	.87	9	0	0	45.0295	25075.7
25932.2	0	72620.4	499.382	37575.7	1.6638	6035.00	.145
0	2E-03	4.58997E-04	.108384	25.7351	25	.735109	6503.06
.29	.15	13995.3	3.53547E-04	2.77008	.466427	6300.89	5134.2
5374.5	.1	43190.4	16809.6	17210.2	5614.75	86.6	0

2.26195	300	0	197960	6.99864E-03	9.91808E-03	6.78584	18.6759
0	0	0	0	0	0	18.6758	.118242
.0373562	18.4	13.52	4.8	.151991	113.076	4.9	7.40629E-04
0	0	0	-1.57042	.756862	519.6	6.51441	101782
450	2	0	0	0	0	0	3791.69
0	2130	177.5	466.307	0	177.693	2143.85	4.80682E+06
0	0	.87	9	0	0	44.6106	27748.4
28575.4	0	76856.3	498.942	37436.9	1.6992	6803.62	.15
0	2E-03	4.58997E-04	.124097	25.6397	25	.639661	7445.83
.33	.155	13986.6	3.53547E-04	3.12284	.486018	6504.47	5039.13
5425.49	.1	43030.9	16969.1	17226.5	5594.02	86.6	0

2.38604	300	0	194259	7.28582E-03	.010107	7.15812	19.4596
0	0	0	0	0	0	19.4596	.120713
.0380678	18.7	13.76	4.9	.15833	112.153	5	7.40817E-04
0	0	0	-1.57042	.756674	519.6	7.1611	107365
450	2	0	0	0	0	0	4114.53
0	2110	175.833	466.435	0	177.565	2124.36	5.23876E+06
0	0	.87	9	0	0	44.1917	30246.9
31412.1	0	81200.1	498.598	37294.7	1.7346	7556.67	.155
0	2E-03	4.58997E-04	.140016	25.5640	25	.564781	8400.97
.37	.16	13977.8	3.53547E-04	3.46849	.506118	6709.87	4944.94
5477.76	.1	42867.4	17132.6	17242.8	5572.77	86.6	0

2.43473	300	0	190594	7.46382E-03	.0103014	7.3042	19.9375
0	0	0	0	0	0	19.9375	.122179
.0387998	19	14	5	.162238	111.23	5	7.40723E-04
0	0	0	-1.57042	.756764	519.6	7.60855	109557
450	2	0	0	0	0	0	4320.18
0	2090	174.167	466.373	0	177.627	2104.86	5.64223E+06
0	0	.87	9	0	0	43.7729	32576.4
33374.9	0	82998.4	498.356	37362.9	1.77	8294.24	.155
0	2E-03	4.58997E-04	.154687	25.5122	25	.512151	9281.23
.41	.16	13969.6	3.53547E-04	3.80703	.514005	6749.04	4851.64
5452.7	1	42945.8	17054.2	17257.8	5582.96	86.6	0

A1	A	AA	AC	AL	AM	AT	B0
A2	B4	B5	B6	B9	BC	BE	BF
BU	C1	C2	D1	D	DA	DX	F1
FA	FC	FD	FI	FS	H	I1	I
IS	K0	K2	K5	K6	K7	K9	K
KE	LA	LA(FT)	LB	LC	LP	LX	M1
M2	MF	MU	N	NA	ND	NO	P
PC	PJ	PK	PL	PW	P1	SM	T1
T	TA	TE	TP	TQ	TR	TS	TT
TW	TX	V	W1	W	WA	WB	WC
WH	WP	WX	[illegible]	WY	WZ	XB	ZI

.345575	300	0	209269	2.85060E-03	9.38200E-03	1.03673	7.3125
0	0	0	0	0	0	7.3126	.0756133
.0353374	10.6	7.28	2.2	.056904	137.074	2.3	7.81851E-04
0	0	0	-1.57041	.763896	519.6	.209073	15550
425.355	2	0	0	0	0	0	532.967
0	2190	182.5	461.495	0	182.505	2645.24	158246
0	0	.88	5	0	0	45.8673	913.659
917.097	0	10708.3	502.058	42782.9	.7700	211.978	.05
0	2E-03	4.58997E-04	2.86951E-03	39.3603	10	29.3603	172.171
.01	.055	16717.7	3.53547E-04	.0972973	.175617	2416.53	5327.02
3639.47	.1	40617	11383	11410.8	5834.04	86.6	0

.881217	300	0	220817	3.92731E-03	8.58057E-03	2.64365	10.4744
0	0	0	0	0	0	10.4744	.0806262
.0323185	13.9	9.92	3.3	.0851012	126.921	3.4	7.49889E-04
0	0	0	-1.57042	.760132	519.6	1.19956	39652.4
450.066	2	0	0	0	0	0	1188.68
0	2290	190.833	464.07	0	179.931	2434.17	904224
0	0	.87	5	0	0	47.9617	5220.69
5261.85	0	28870.1	389.871	39922.8	1.1682	1108.29	.085
0	2E-03	4.58997E-04	.016731	14.9719	10	4.97189	1003.86
.05	.09	15500.3	3.53547E-04	.5007	.262277	3775.21	5824.62
4511.92	.1	45888.3	14111.7	14156.7	5965.47	86.6	0

1.19381	300	0	224838	4.61471E-03	8.73243E-03	3.58142	12.3303
0	0	0	0	0	0	12.3303	.0960698
.0328905	15.4	11.12	3.8	.100363	122.306	3.9	7.48517E-04
0	0	0	-1.57042	.759143	519.6	2.15482	53718.1
457.513	2	0	0	0	0	0	1653.28
0	2270	189.167	464.746	0	179.254	2337.76	1.58547E+06
0	0	.87	5	0	0	47.5428	9153.98
9452.11	0	39709.5	379.216	39171	1.3452	1977.49	.1
0	2E-03	4.58997E-04	.0312436	12.6555	10	2.65554	1374.61
.09	.105	15322.3	3.53547E-04	.987664	.313008	4464.38	5723.12
4788.22	.1	45024.1	14975.9	15006	5853.13	86.6	0

1.41686	300	0	218974	5.12796E-03	8.96751E-03	4.25059	13.6973
0	0	0	0	0	0	13.6973	.101232
.0337774	16.3	11.84	4.1	.111542	119.537	4.1	7.48171E-04
0	0	0	-1.57042	.75864	519.6	2.97717	63754.9
458	2	0	0	0	0	0	2042.08
0	2240	186.667	465.091	0	178.91	2279.75	2.20082E+06
0	0	.87	5	0	0	46.9145	12706.8
13059.[illegible]	0	47479.8	370.918	38788.3	1.4514	2818.63	.11
0	2E-03	4.58997E-04	.0459587	11.7896	10	1.78955	2757.52
.13	.115	15060.7	3.53547E-04	1.29374	.349136	4913.86	5573.04
4928.85	.1	44584.3	15415.7	15477.9	5795.95	86.6	0

1.55352	300	0	211185	5.51214E-03	9.29698E-03	4.66055	14.7353
0	0	0	0	0	0	14.7353	.104997
.0350163	16.9	12.32	4.3	.119997	117.691	4.4	7.40156E-04
0	0	0	-1.57042	.758604	519.6	3.59057	69904.2
458	2	0	0	0	0	0	2363.4
0	2200	183.333	465.115	0	178.005	2241	2.72707E+06
0	0	.87	5	0	0	46.0767	15745.2
15750	0	52200.7	360.282	38761.5	1.5222	3620.08	.115
0	2E-03	4.58997E-04	.0601758	11.3658	10	1.36581	3610.55
.17	.12	14000	3.53547E-04	1.66161	.371272	5132.09	5375.78
4938.7	.1	44553.4	15446.6	15917.9	5791.95	86.6	0
1.76715	300	0	209269	5.91764E-03	9.38200E-03	5.30144	15.8214
0	0	0	0	0	0	15.8214	.10879
.0353374	17.5	12.8	4.5	12806	115.845	4.6	7.40054E-04
0	0	0	-1.57042	.757924	519.6	4.47309	79516.9
458	2	0	0	0	0	0	2725.4
0	2190	182.5	465.58	0	178.42	2202.19	3.32316E+06
0	0	.87	5	0	0	45.8673	19186.8
19621.2	0	59718.8	352.732	38244.8	1.593	4451.54	.125
0	2E-03	4.58997E-04	.0761434	11.065	10	1.06581	4568.6
.21	.13	14524.1	3.53547E-04	2.04324	.405874	5584.89	5327.02
5128.6	.1	43959.5	16040.5	16416.5	5714.73	86.6	0
1.95093	300	0	205464	6.3061E-03	9.55582E-03	5.85279	16.8571
0	0	0	0	0	0	16.8571	.112304
.0359918	17.8	13.04	4.6	.137271	114.922	4.7	7.40185E-04
0	0	0	-1.57042	.75749	519.6	5.16021	87786.6
458	2	0	0	0	0	0	3092.8
0	2170	180.833	465.877	0	178.123	2182.75	3.84913E+06
0	0	.87	5	0	0	45.4484	22223.6
22635.2	0	66054	347.928	37914.8	1.6284	5251.05	.135
0	2E-03	4.58997E-04	.0920218	10.8736	10	.873635	5521.31
.25	.14	14241.8	3.53547E-04	2.41022	.435641	5939.76	5230.17
5249.87	.1	43580.2	16419.8	16919.1	5665.43	86.6	0
2.141	300	0	201694	6.70364E-03	9.73443E-03	6.42299	17.9129
0	0	0	0	0	0	17.9129	.11579
.0366645	18.1	13.28	4.7	.145814	113.999	4.8	7.40469E-04
0	0	0	-1.57042	.757044	519.6	5.91182	96339.1
458	2	0	0	0	0	0	3489.72
0	2150	179.167	466.192	0	177.818	2163.31	4.34311E+06
0	0	.87	5	0	0	45.0295	25075.7
25932.2	0	72620.4	344.451	37575.7	1.6638	6035.03	.145
0	2E-03	4.58997E-04	.108324	10.7351	10	.735109	6503.06
.29	.15	14094.4	3.53547E-04	2.77008	.466427	6300.89	5134.2
5374.5	.1	43190.4	16809.6	17106.4	5614.75	86.6	0
2.26195	300	0	197960	6.99064E-03	9.91000E-03	6.78584	18.6759
0	0	0	0	0	0	18.6758	.118242
.0373562	18.4	13.52	4.8	.151991	113.076	4.9	7.40629E-04
0	0	0	-1.57042	.756862	519.6	6.51441	101782
458	2	0	0	0	0	0	3791.69
0	2130	177.5	466.307	0	177.693	2143.85	4.80602E+06
0	0	.87	5	0	0	44.6106	27748.4
28575.4	0	76856.3	342.856	37436.9	1.6992	6803.62	.15
0	2E-03	4.58997E-04	.124097	10.6397	10	.639661	7445.83
.33	.155	14083.9	3.53547E-04	3.12204	.486018	6504.47	5039.13
5425.49	.1	43030.9	16969.1	17207.6	5594.02	86.6	0

2.39604	300	0	194259	7.28502E-03	.010107	7.15012	19.4596
0	0	0	0	0	0	19.4596	.120713
.0300670	10.7	13.76	4.9	.15033	112.153	5	7.40017E-04
0	0	0	-1.57042	.756674	519.6	7.1611	107365
450	2	0	0	0	0	0	4114.53
0	2110	175.833	466.435	0	177.565	2124.36	5.23076E+06
0	0	.87	5	0	0	44.1917	30246.9
31412.1	0	81200.1	340.176	37294.7	1.7346	7556.67	.155
0	2E-03	4.58997E-04	.140016	10.5640	10	.564701	8400.97
.37	.16	14073.3	3.53547E-04	3.46049	.506118	6709.07	4944.94
5477.76	.1	42067.4	17132.6	17220.6	5572.77	86.6	0

2.43473	300	0	198594	7.46302E-03	.0103014	7.3042	19.9375
0	0	0	0	0	0	19.9375	.122179
.0387990	19	14	5	.162238	111.23	5	7.40723E-04
.0	0	0	-1.57042	.756764	519.6	7.60055	109557
450	2	0	0	0	0	0	4320.18
0	2090	174.167	466.373	0	177.627	2104.86	5.64223E+06
0	0	.87	5	0	0	43.7729	32576.4
33374.9	0	82998.4	338.055	37362.9	1.77	8294.24	.155
0	2E-03	4.58997E-04	.154607	10.5122	10	.512151	9201.23
.41	.16	14063.5	3.53547E-04	3.80703	.514005	6749.04	4851.64
5452.7	.1	42945.8	17054.2	17247.5	5502.96	86.6	0

A1	A	AA	AC	AL	AM	AT	B0
B2	B4	B5	B6	B9	BC	BE	BF
BU	C1	C2	D1	D	DA	DX	F1
FA	FC	FD	FI	FS	H	I1	I
IS	K0	K2	K5	K6	K7	K9	K
KE	LA	LA(FT)	LB	LC	LP	LX	M1
M2	MF	MU	N	NA	ND	NO	P
PC	PJ	PK	PL	PW	R1	SM	T1
T	TA	TE	TP	TQ	TR	TS	TT
TW	TX	V	W1	W	WA	WB	WC
WH	WP	WX	WW	WY	WZ	XB	ZI

.329867	300	0	170041	3.25192E-03	0110277	.989682	8.19082
0	0	0	0	0	0	8.19082	0006464
0415355	10.3	7.04	2.1	0620478	137.997	2.1	7.9404E-04
0	0	0	-1.5704	.765623	519.6	181839	14043.2
424.762	2	0	0	0	0	0	640.299
0	2020	168.333	460.314	0	183.686	2664.37	124297
0	0	88	2	0	0	42.3068	717.65
797.637	0	10143.1	449.401	44095.7	7434	195.523	05
0	2E-03	4.58997E-04	2.65072E-03	37.7133	5	32.7133	159.043
01	055	17791.8	3.53547E-04	0697445	173073	2196.65	453[illegible].1
[illegible]62.51	1	50100.7	9891.26	9912.57	6013.05	86.6	0

304248	300	0	201694	4.41679E-03	9.73443E-03	2.41274	11.383
0	0	0	0	0	0	11.383	0939071
0366645	13.6	9.68	3.2	0093686	127.844	3.3	7.7603E-04
0	0	0	-1.57041	762591	519.6	1.02944	36109
448.369	2	0	0	0	0	0	1310.89
0	2150	179.167	462.300	0	181.612	2453.41	74801[illegible]
0	0	88	2	0	0	45.0295	4323.39
4515.62	0	26254.5	298.996	41791.2	1.1328	1040.53	08
0	2E-03	4.58997E-04	015174	10.717	5	5.71690	910.44
05	005	16944.8	3.53547E-04	477601	24991	3376	5134.2
3999.79	1	47490	12510	12500.1	5690.0	86.6	0

1.13097	300	0	203575	5.15299E-03	9.6445E-03	3.39292	13.3425
0	0	0	0	0	0	13.3425	101518
.0363258	14.8	10.64	3.6	.105243	124.152	3.6	7.72415E-04
0	0	0	-1.57041	.76126	519.6	1.03218	50890.8
457.052	2	0	0	0	0	0	1817.95
0	2160	180	463.298	0	180.702	2376.36	1.36669E+06
0	0	.88	2	0	0	45.2389	7890.8
8036.04	0	37409.6	230.625	40779.9	1.2744	1001.67	.1
0	2E-03	4.58997E-04	.0208302	7.99303	5	2.99303	1729.01
.09	.105	16535.1	3.53547E-04	.86368	.302831	4109.92	5182.08
4367.24	1	46340.8	13659.2	13732.3	5560.09	86.6	0

1.3923	300	0	194259	5.89104E-03	.010107	4.1469	15.2658
0	0	0	0	0	0	15.2658	.108545
.0380678	16	11.6	4	.120511	120.46	4.1	7.71793E-04
0	0	0	-1.57041	.760907	519.6	2.7646	62199.9
458	2	0	0	0	0	0	2383.67
0	2110	175.833	463.54	0	180.46	2299.1	1.04064E+06
0	0	.88	2	0	0	44.1917	10627.3
12126.9	0	46212.8	206.562	40511.6	1.416	2655.05	.11
0	2E-03	4.58997E-04	.042225	7.03433	5	2.03433	2533.5
.13	.115	16133.3	3.53547E-04	1.21066	.343539	4554.48	4944.94
4464.72	.1	46025.9	13964.1	14421.6	5524.3	86.6	0

1.51729	300	0	197968	5.73136E-03	9.91800E-03	4.55217	15.384
0	0	0	0	0	0	15.384	.107064
.0377562	16.6	12.08	4.2	.124488	118.614	4.2	7.49082E-04
0	0	0	-1.57042	.759578	519.6	3.34585	68278.5
458	2	0	0	0	0	0	2543.59
0	2130	177.5	464.449	0	179.551	2260.38	2.47583E+06
0	0	.87	2	0	0	44.6106	14294.6
14676.5	0	50963.1	191.696	39501	1.4068	3504.9	.115
0	2E-03	4.58997E-04	.0580665	6.44208	5	1.44208	3404.83
.17	.12	15657.6	3.53547E-04	1.60074	.36542	4890.48	5039.13
4666.92	.1	45403.5	14596.5	14672	5982.45	86.6	0

1.69646	300	0	203575	5.9206E-03	9.6445E-03	5.08938	15.8276
0	0	0	0	0	0	15.8276	.108817
.0363258	17.5	12.8	4.5	.120896	115.945	4.5	7.48137E-04
0	0	0	-1.57042	.758559	519.6	4.29417	76336.2
458	2	0	0	0	0	0	2726.92
0	2160	180	465.146	0	178.854	2202.19	3.18894E+06
0	0	.87	2	0	0	45.2389	18411.9
18036.3	0	57330.1	183.182	38726.7	1.593	4390.56	.12
0	2E-03	4.58997E-04	.0744566	6.10286	5	1.10286	4467.4
.21	.125	15166.3	3.53547E-04	2.01525	.394424	5353	5182.08
4951.49	.1	44513.4	15406.6	15408.5	5706.75	86.6	0

1.77186	300	0	199823	6.13555E-03	9.82561E-03	5.31557	16.4025
0	0	0	0	0	0	16.4025	.110775
.0370079	18.1	13.28	4.7	.13358	113.999	4.7	7.48124E-04
0	0	0	-1.57042	.758526	519.6	4.09254	79728.9
458	2	0	0	0	0	0	2928.72
0	2140	178.333	465.168	0	178.832	2163.31	3.69225E+06
0	0	.87	2	0	0	44.8201	21317.9
21461.1	0	60099.7	178.711	38702.2	1.6638	5178.46	.12
0	2E-03	4.58997E-04	.0887407	5.92475	5	.924751	5324.44
.25	.125	14737.8	3.53547E-04	2.3769	.406637	5467.65	5806.56
4960.48	.1	44405.3	15514.7	16220	5783.09	86.6	0

2.03575	300	0	197960	6.62267E-03	9.91000E-03	6.10726	17.7051
0	0	0	0	0	0	17.7051	.115000
.0373562	18.4	13.52	4.8	.144192	113.076	4.9	7.40107E-04
0	0	0	-1.57042	.757687	519.6	5.86297	91603.4
450	2	0	0	0	0	0	3412.52
0	2130	177.5	463.742	0	178.258	2143.05	4.22340E+06
0	0	.87	2	0	0	44.6106	24385
25717.9	0	69170.7	174.607	38064	1.6992	5978.94	.125
0	2E-03	4.58997E-04	.186024	5.76124	5	.761239	6361.45
.29	.14	14394	3.53547E-04	2.74432	.449381	6814.14	5039.13
5195.04	1	43751.7	16248.3	16822.9	5687.72	86.6	0
2.2321	300	0	194259	7.03776E-03	.010107	6.69631	18.8092
0	0	0	0	0	0	18.8092	.11864
.0380678	18.7	13.76	4.9	.153137	112.153	4.9	7.40332E-04
0	0	0	-1.57042	.757231	519.6	6.69909	100439
450	2	0	0	0	0	0	3849.08
0	2110	175.833	466.054	0	177.946	2124.36	4.67241E+06
0	0	.87	2	0	0	44.1917	26977
29385.5	0	75968.9	171.879	37717.4	1.7346	6739.74	.145
0	2E-03	4.58997E-04	.122554	5.65257	5	.652568	7353.25
.33	.15	14377.4	3.53547E-04	3.09352	.401184	6379.3	4944.94
5322.79	1	43353.4	16646.6	16854.8	5635.94	86.6	0
2.27765	300	0	190594	7.21034E-03	.0103014	6.83296	19.272
0	0	0	0	0	0	19.272	.120006
.0387998	19	14	5	.156918	111.23	5.1	7.40272E-04
0	0	0	-1.57042	.757326	519.6	7.11768	102408
450	2	0	0	0	0	0	4041.46
0	2090	174.167	465.989	0	178.011	2104.86	5.09177E+06
0	0	.87	2	0	0	43.7729	29398.2
31221.6	0	77643.7	170.185	37790.2	1.77	7485.05	.145
0	2E-03	4.58997E-04	.136961	5.58585	5	.585852	8217.64
.37	.15	14363	3.53547E-04	3.43562	.408562	6415.73	4951.64
5295.67	1	43437	16563	16881.9	5646.81	86.6	0
2.32321	300	0	186964	7.38601E-03	.0105014	6.96962	19.7451
0	0	0	0	0	0	19.7451	.121547
.0395532	19.3	14.24	5.1	.160791	110.387	5.1	7.40218E-04
0	0	0	-1.57042	.757424	519.6	7.55333	104528
450	2	0	0	0	0	0	4242.94
0	2070	172.5	465.922	0	178.078	2085.34	5.48242E+06
0	0	.87	2	0	0	43.354	31653.7
33132.6	0	79318.9	168.922	37964.1	1.8054	8214.97	.145
0	2E-03	4.58997E-04	.151262	5.52078	5	.530775	9975.71
.41	.15	14348.7	3.53547E-04	3.7706	.495941	6450.3	4759.22
5268.48	1	43522	16478	16908.6	5657.96	86.6	0

APPENDIX 10-2. SPACE BASED RADAR-R ANALYSIS (Baseline with Unit Area Weight of Lens WL = 6.6×10^{-4})

B1	B	BP	CD	D2	DB	DD	DM
DT	DW	E	EE	EM	FB	G	GE
K1	KP	KQ	KS	KT	LD	LF	LM
LQ	NH	NV	PI	RH	RM	RS	S1
SP	T2	T0	TD	TF	TG	TL	TM
TN	TY	TZ	WL	WN	WS	WT	WU
ZH							

100	1	1	.014	1	36	.1	2
3	.01	[illegible]E+07	.107	300000	1	32.17	3.54E+06
.2	21	[illegible]	15	4.1	10	40	1700
604	.6	.85	3.14159	.063	.0513	80	4E+07
3330	.025	2E-03	5E-03	.04	9E-03	.125	.05
.01	.4[illegible]	.02	6.6E-04	10	60000	1	10502
.47							

A1	A	AA	AC	AL	AM	AT	B0
B2	B4	B5	B6	B9	BC	BE	BF
BU	C1	C2	D1	D	DA	DX	F1
FA	FC	FD	FI	FS	H	I1	I
IS	K0	K2	K5	K6	K7	K9	K
KE	LA	LA(FT)	LB	LC	LP	LX	M1
M2	MF	MU	N	NA	ND	NO	P
PC	PJ	PK	PL	PW	R1	SM	T1
T	TA	TE	TP	TQ	TR	TS	TT
TW	TX	Y	W1	W	WA	WB	WC
WH	WP	WX	WW	WY	WZ	XB	ZI

.397412	300	0	144531	3.95198E-03	.0135845	1.19223	10.2294
0	0	0	0	0	0	10.2294	.0089042
.0511657	10.9	7.52	2.3	.0006603	136.151	2.4	7.72671E-04
0	0	0	-1.5[illegible]	.761387	519.6	.262788	17882.5
426.203	2	0	0	0	0	0	1067.86
0	1820	151.667	463.211	0	160.789	2626.11	176020
0	0	.88	9	0	0	38.118	1016.28
1152.72	0	1.34077E+07	612.406	40876.4	.8142	340.596	.035
0	2E-03	4.58997E-04	3.18727E-03	50.3056	25	25.3055	191.236
.01	.06	15267.6	6.83547E-04	.156333	.184014	2104.27	7113.14
4332.18	.1	46450.4	13549.6	13596.4	5574.05	86.6	0

.961327	300	0	154217	5.48739E-03	.0127313	2.88398	14.6713
0	0	0	0	0	0	14.6713	.104761
.047952	14.2	10.16	3.4	.119494	125.998	3.5	7.48044E-04
0	0	0	-1.57042	.750041	519.6	1.38912	43257.2
451.337	2	0	0	0	0	0	2343.62
0	1800	156.667	465.5	0	178.5	2414.91	969585
0	0	.87	9	0	0	39.3746	5598.06
6093.36	0	3.41634E+07	516.407	38333.6	1.2036	1759.12	.09
0	2E-03	4.58997E-04	.0180553	29.4363	25	4.43631	1083.32
.05	.095	14455.2	6.83547E-04	.007432	.275353	3252.57	7589.86
5095.94	1	44061.6	15938.4	16001.6	5728.01	86.6	0

1.2535	300	0	150354	6.37017E-03	.0130065	3.76049	17.0278
0	0	0	0	0	0	17.0278	.112873
.0489088	15.4	11.12	3.8	.138656	122.306	3.8	7.4821E-04
0	0	0	-1.57042	.757439	519.6	2.26256	56404
457.748	2	0	0	0	0	0	3155.54
0	1860	155	465.912	0	178.088	2337.76	1.6904E+06
0	0	.87	9	0	0	38.9558	9759.82
9924.71	0	4.50757E+07	507.126	37876	1.3452	3132.73	.105
0	2E-03	4.58997E-04	.033106	27.4187	25	2.4187	1991.16
.09	.11	14371.2	6.83547E-04	1.43792	.322676	3771.03	7429.23
5264.12	.1	43535.6	16464.4	16516.7	5659.63	86.6	0
1.48126	300	0	146123	7.09811E-03	.0134364	4.44378	18.9704
0	0	0	0	0	0	18.9704	.119148
.0506081	16.3	11.84	4.1	.154449	119.537	4.2	7.48334E-04
0	0	0	-1.57042	.757228	519.6	3.1125	66652.8
458	2	0	0	0	0	0	3915.32
0	1830	152.5	466.056	0	177.944	2279.75	2.32599E+06
0	0	.87	9	0	0	38.3274	13429.5
13653	0	5.36627E+07	503.619	37715.3	1.4514	4452.07	.115
0	2E-03	4.58997E-04	.0482835	26.6563	25	1.65627	2897.01
.13	.12	14287.3	6.83547E-04	2.04349	.359568	4134.39	7191.52
5323.18	.1	43350.9	16649.1	16682.6	5635.62	86.6	0
1.68861	300	0	141372	7.77004E-03	.0138881	5.06582	20.7658
0	0	0	0	0	0	20.7658	.124666
.0523091	16.9	12.32	4.3	.169045	117.691	4.4	7.48429E-04
0	0	0	-1.57042	.757096	519.6	3.90279	75982.8
458	2	0	0	0	0	0	4690.29
0	1800	150	466.146	0	177.854	2241	2.89525E+06
0	0	.87	9	0	0	37.6991	16716.2
17119.6	0	6.14439E+07	501.785	37615.3	1.5222	5726.5	.125
0	2E-03	4.58997E-04	.0634234	26.2576	25	1.25755	3885.4
.17	.13	14203.2	6.83547E-04	2.62845	.393152	4446.45	6957.67
5359.93	.1	43236	16764	16834.1	5620.67	86.6	0
1.83783	300	0	138248	8.24597E-03	.0142019	5.5135	22.0327
0	0	0	0	0	0	22.0327	.128421
.0534912	17.5	12.8	4.5	.179337	115.845	4.5	7.4852E-04
0	0	0	-1.57042	.756983	519.6	4.65201	82697.6
458	2	0	0	0	0	0	5278.8
0	1780	148.333	466.224	0	177.776	2202.19	3.45918E+06
0	0	.87	9	0	0	37.2802	19972.2
20406	0	6.71433E+07	500.654	37529.4	1.593	6995.32	.13
0	2E-03	4.58997E-04	.0786471	26.0118	25	1.01101	4718.83
.21	.135	14118.6	6.83547E-04	3.21083	.417323	4667.37	6803.9
5391.5	.1	43137.2	16862.8	16906.7	5607.84	86.6	0
1.99334	300	0	136699	8.66725E-03	.0143628	5.90002	23.1495
0	0	0	0	0	0	23.1495	.131661
.0540973	18.1	12.28	4.7	.188355	113.999	4.8	7.48006E-04
0	0	0	-1.57042	.756684	519.6	5.50411	89695
458	2	0	0	0	0	0	5823.06
0	1770	147.5	466.428	0	177.572	2163.31	4.04942E+06
0	0	.87	9	0	0	37.0708	23380
24143.7	0	7.30942E+07	499.047	37302.2	1.6638	8280.97	.135
0	2E-03	4.58997E-04	.0945743	25.8363	25	.836321	5674.46
.25	.14	14033.1	6.83547E-04	3.80094	.442511	4921.27	6727.67
5475	.1	42876.1	17123.9	17146.8	5573.09	86.6	0

2.11115	300	0	133627	9.07317E-03	.014693	6.33345	24.2335
0	0	0	0	0	0	24.2335	.134708
.0553409	18.4	13.52	4.8	.197174	113.076	4.9	7.48811E-04
0	0	0	-1.57042	.756679	519.6	6.00011	94996.2
458	2	0	0	0	0	0	6381.08
0	1750	145.833	466.432	0	177.568	2143.85	4.5407E+06
0	0	.87	9	0	0	36.6519	26216.5
26670.4	0	7.75487E+07	499.316	37298.3	1.6992	9497.38	.14
0	2E-03	4.58997E-04	.109725	25.7208	25	.720768	6583.5
.29	.145	13994.6	6.83547E-04	4.35927	.461593	5075.48	6576.49
5476.43	.1	42871.6	17128.4	17211.6	5573.31	86.6	0
2.2321	300	0	130590	9.49197E-03	.0150347	6.69631	25.3518
0	0	0	0	0	0	25.3518	.137782
.0566279	18.7	13.76	4.9	.20627	112.153	5	7.48821E-04
0	0	0	-1.57042	.75667	519.6	6.69909	100439
458	2	0	0	0	0	0	6983.37
0	1730	144.167	466.438	0	177.562	2124.36	4.9928E+06
0	0	.87	9	0	0	36.233	28826.8
29385.5	0	8.21285E+07	498.912	37291.3	1.7346	10683.9	.145
0	2E-03	4.58997E-04	.124898	25.6331	25	.633087	7493.88
.33	.15	13986.2	6.83547E-04	4.90386	.481184	5230.43	6427.03
5479	.1	42863.5	17136.5	17227.3	5572.26	86.6	0
2.3562	300	0	127588	9.92422E-03	.0153884	7.06858	26.5057
0	0	0	0	0	0	26.5057	.140884
.0579682	19	14	5	.215655	111.23	5.1	7.48836E-04
0	0	0	-1.57042	.756657	519.6	7.36311	106023
458	2	0	0	0	0	0	7633.3
0	1710	142.5	466.447	0	177.553	2104.86	5.40711E+06
0	0	.87	9	0	0	35.8142	31218.9
32298.2	0	8.68336E+07	498.596	37281.4	1.77	11840.4	.15
0	2E-03	4.58997E-04	.140898	25.5642	25	.56425	8405.89
.37	.155	13977.7	6.83547E-04	5.4347	.501284	5385.91	6279.29
5482.64	.1	42852.2	17147.8	17242.9	5570.78	86.6	0
2.40332	300	0	126100	.0101104	.01557	7.20996	27.0045
0	0	0	0	0	0	27.0045	.1422
.0586441	19.3	14.24	5.1	.219725	110.307	5.1	7.48793E-04
0	0	0	-1.57042	.756696	519.6	7.81379	108143
458	2	0	0	0	0	0	7924.16
0	1700	141.667	466.42	0	177.58	2085.34	5.88774E+06
0	0	.87	9	0	0	35.6047	33993.9
34275.1	0	8.87071E+07	498.347	37311	1.8054	13043.7	.15
0	2E-03	4.58997E-04	.155041	25.5103	25	.510272	9382.48
.41	.155	13969.4	6.83547E-04	5.98702	.508916	5435.95	6206.06
5471.75	1	42886.2	17113.8	17258.2	5575.21	86.6	0

APPENDIX 11. GEO PLATFORM ANALYSIS (Baseline Configuration)

B1	B	BP	CD	D2	DB	DD	DM
DT	DV	E	EE	EM	FB	G	GE
K1	KP	KQ	KS	KT	LD	LF	LM
LQ	MH	MV	PI	RH	RM	RS	S1
SP	T2	T0	TD	TF	TG	TL	TM
TN	TY	TZ	WL	WN	WS	WT	WU
ZH							

100	1	1	.014	1	36	.1	2
3	.01	4E+07	.107	300000	3.218	32.17	2.54E+06
.2	21	.5	15	4.1	10	40	10
684	.6	.85	3.14159	.063	.0513	88	37000
3330	.025	2E-03	5E-03	.04	9E-03	.125	.05
.01	.41	.02	3.3E-04	10	60000	1200	10502
.47							

A1	A	AA	AC	AL	AM	AT	B0
B2	B4	B5	B6	B9	BC	BE	BF
BU	C1	C2	D1	D	DA	DX	F1
FH	FC	FD	FI	FS	H	I1	I
IS	K0	K2	K5	K6	K7	K9	K
KE	LA	LA(FT)	LB	LC	LP	LX	M1
M2	MF	MU	N	NA	ND	NO	P
PC	PJ	PK	PL	PW	P1	SM	T1
T	TA	TE	TP	TQ	TR	TS	TT
TW	TX	V	W1	W	WA	WB	WC
WH	WP	WX	WW	WY	WZ	XB	ZI

0	53.766	.0489208	25202.6	.0008211	0	0	6.03927
.0388285	0	0	0	0	0	6.03981	.402047
0	10	6.8	2	1.64998	0	2.1	.0267636
1.32104	2.04209	50.7736	-1.55741	.404791	93.1227	.15708	0
426.219	2	0	0	0	0	0	372.367
0	760	63.3333	503.243	96.1203	180.757	2979.02	26590.8
21052.3	1.95122E-05	.88	9	0	.0692181	0	285.546
9579.13	226.071	9579.13	612.092	40840.7	.708	119.71	.05
0	2E-03	4.58997E-04	3.19722E-03	50.2372	25	25.2273	191.592
.01	.055	15267	3.53547E-04	0	.332116	252.408	520.524
4345.14	.557974	46401.3	13590.1	13598.7	5569.19	0	0

0	53.766	.0971392	61789	.0286724	0	0	2.98457
.0779994	0	0	0	0	0	2.98478	.279109
0	10	6.8	2	.842129	0	2.1	.0259138
12.5164	25.0329	312.99	-1.55784	.400951	93.1227	.15708	0
451.366	2	0	0	0	0	0	96.9999
0	1190	99.1667	505.524	150.504	178.466	3997.13	226190
182496	1.52768E-04	.87	9	0	.273113	0	2428.95
9579.13	1970.48	9579.13	516.353	28295.8	.708	472.544	.05
0	2E-03	4.58997E-04	.0180869	29.4245	25	4.42449	1085.21
.05	.055	14455.1	3.53547E-04	0	.332116	295.217	1100.71
5109.05	.557974	43936.4	15981.9	16003.6	5722.36	0	0

0	53.766	.120755	70375	.0350927	0	0	2.70764
.0958431	0	0	0	0	0	2.70787	.264925
0	10	6.8	2	.763825	0	2.1	.0259198
25.6606	51.3212	515.627	-1.55784	.495171	93.1227	.15708	0
457.751	2	0	0	0	0	0	79.7997
0	1270	105.833	505.925	160.622	176.075	4000.23	437271
360126	2.93469E-04	.87	9	0	.422277	0	4695.65
9579.13	3967.22	9579.13	507.114	37960.7	.708	720.851	.05
0	2E-03	4.58997E-04	.0332059	27.4161	25	2.41507	1992.53
.09	.055	14371.1	3.53547E-04	0	.332116	421.787	1481.47
5269.73	.557974	43483	16481.9	16517	5657.35	0	0
0	53.766	.127568	73740.2	.0338971	0	0	2.61492
.109183	0	0	0	0	0	2.61514	.260272
0	10	6.8	2	.727537	0	2.1	.0259244
38.8371	77.6742	684.391	-1.55783	.500498	93.1227	.15708	0
458	2	0	0	0	0	0	74.4615
0	1200	108.333	506.076	164.416	177.924	4001.42	545323
536814	4.33912E-04	.87	9	0	.548305	0	6929.87
9579.13	5764.59	9579.13	503.607	37693.7	.708	949.24	.05
0	2E-03	4.58997E-04	.0483303	26.6537	25	1.65372	3899.92
.13	.055	14287.1	3.53547E-04	0	.332116	431.75	1552.29
5321.11	.557974	43317	16673.9	16683	5632.39	0	0
0	53.766	.151204	76026.5	.0331394	0	0	2.55609
.120911	0	0	0	0	0	2.55631	.257447
0	10	6.8	2	.720839	0	2.1	.0259283
52.3617	104.723	838.81	-1.55783	.504048	93.1227	.15708	0
458	2	0	0	0	0	0	71.0706
0	1320	110	506.177	166.946	177.823	4002.22	855799
716678	5.76154E-04	.87	9	0	.662663	0	9190.02
9579.13	7696.07	9579.13	501.771	37581.2	.708	1147.5	.05
0	2E-03	4.58997E-04	.06352	26.2545	25	1.3545	3811.2
.17	.055	14202.7	3.53547E-04	0	.332116	438.393	1600.42
5272.46	.557974	43164.9	16803.2	16835.1	5615.58	0	0
0	53.5184	.160583	71488.7	.0371379	0	0	2.96404
.127455	0	0	0	0	0	2.96428	.272536
0	10.3	7.04	2.1	.807552	0	2.2	.0259125
60.8213	121.643	916.959	-1.55783	.505996	92.6938	.200023	0
458	2	0	0	0	0	0	89.1973
0	1290	106.667	506.274	168.376	177.726	3848.72	1.01447E+06
868846	6.98152E-04	.87	9	0	.747648	0	10944.3
11157.4	9286.99	11157.4	500.636	37472.9	.7434	1294.9	.055
0	2E-03	4.58997E-04	.0788448	26.0078	25	[illegible]	4730.69
.21	.06	14117.5	3.53547E-04	0	.365957	468.425	1504.89
5412.26	.560555	43011.4	16927.7	16988.7	5599.4	0	0
0	53.2711	.168652	68176.8	.0409743	0	0	3.15896
.134018	0	0	0	0	0	3.15922	.286267
0	10.6	7.28	2.2	.890441	0	2.3	.0259402
69.0521	128.104	989.386	-1.55783	.50935	92.2656	.250888	0
458	2	0	0	0	0	0	108.449
0	1250	104.167	506.429	170.824	177.571	3705.78	1.17391E+06
1.0066E+06	8.02353E-04	.87	9	0	.826866	0	12723.2
12849.9	10909.8	12849.9	499.847	37380.8	.7798	1432.34	.06
0	2E-03	4.58997E-04	.0945882	25.8362	25	.836227	5674.91
.25	.065	14030.1	3.53547E-04	0	.401982	502.477	1435.18
5475.52	.561157	42353.1	17125.6	17146.9	5573.68	0	0

0	53.0242	.175018	62831.8	.046154	0	0	3.55793
.138912	0	0	0	0	0	3.55823	.303822
0	10.9	7.52	2.3	1.0028	0	2.4	.0259429
73.8205	147.641	1019.99	-1.55783	.508146	91.8379	.310568	0
458	2	0	0	0	0	0	137.544
0	1200	100	506.478	170.196	177.522	2571.22	1.29293E+06
1.12121E+06	8.935E-04	.87	9	0	.988557	0	14078.3
14657.1	12208.5	14657.1	499.204	37247.1	.8142	1539.41	.065
0	2E-03	4.58997E-04	.109973	25.7182	25	.718158	6598.25
.29	.07	13994.5	3.53547E-04	0	.44019	528.228	1322.66
5495.25	.56578	42788.1	17187.3	17211.9	5565.65	0	0

0	52.7777	.179623	56705.8	.0525988	0	0	4.05424
.142567	0	0	0	0	0	4.05458	.324317
0	11.2	7.76	2.4	1.14272	0	2.5	.0259422
75.8124	151.625	1020.2	-1.55783	.504600	91.4109	.380007	0
458	2	0	0	0	0	0	178.604
0	1140	95	506.465	167.616	177.535	2444.59	1.37817E+06
1.20967E+06	9.65904E-04	.87	9	0	.936094	0	15076.6
16579	13222.4	16579	498.906	37261.3	.8496	1621.93	.07
0	2E-03	4.58997E-04	.125063	25.6317	25	.631746	7503.76
.33	.075	13986.1	3.53547E-04	0	.480581	547.863	1193.7
5490.01	.568422	42772.5	17170.9	17227.5	5567.78	0	0

0	52.5215	.185508	54733.5	.0548633	0	0	4.22939
.147228	0	0	0	0	0	4.22975	.33125
0	11.5	8	2.5	1.19207	0	2.5	.0259424
82.0454	164.091	1068.67	-1.55783	.508912	90.9846	.422515	0
458	2	0	0	0	0	0	194.366
0	1120	93.3333	506.469	170.564	177.531	3325.7	1.50892E+06
1.32068E+06	1.06398E-03	.87	9	0	.998661	0	16584.4
17374.8	14625.4	17374.8	498.591	37256.8	.865	1720.57	.07
0	2E-03	4.58997E-04	.14025	25.5633	25	.563269	8414.97
.37	.075	13977.6	3.53547E-04	0	.495864	555.368	1152.18
5491.66	.571096	42756.9	17176.1	17243.1	5567.11	0	0

0	52.2857	.190816	52796.2	.0572138	0	0	4.41059
.151451	0	0	0	0	0	4.41096	.338271
0	11.8	8.24	2.6	1.24314	0	2.7	.0259424
87.6972	175.394	1110.04	-1.55783	.512991	90.5558	.483146	0
458	2	0	0	0	0	0	211.376
0	1100	91.6667	506.47	173.355	177.53	3213.73	1.63277E+06
1.44723E+06	1.15796E-03	.87	9	0	1.05685	0	18029.9
18171.7	15981.1	18171.7	498.338	37256.1	.9204	1831.63	.07
0	2E-03	4.58997E-04	.155417	25.5083	25	.50829	9325.01
.41	.075	13969.2	3.53547E-04	0	.511148	562.262	1111.4
5491.94	.573771	42741.4	17176.9	17258.6	5567	0	0

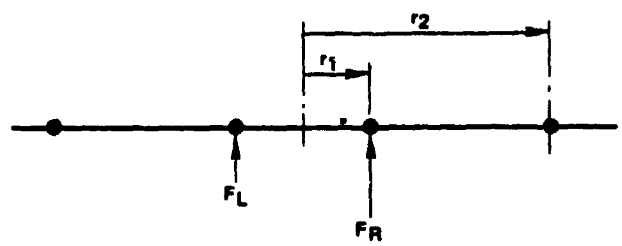
APPENDIX 12

DISTRIBUTED THRUST ANALYSIS

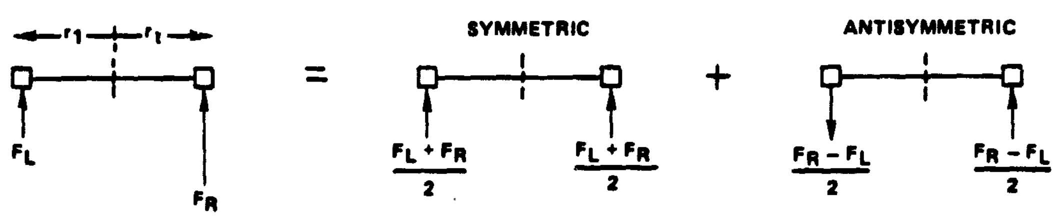
The effect of distributed thrust on dynamic loading was examined. Distributed thrust results in decreased dynamic loading over the center thrusted case, as long as the thrusters are in phase. If they are slightly out of phase, however, dynamic loading is increased. Since exact phasing of the thrusters is not probable, this situation was examined.

The computer program examines the dynamic factor for a typical OTV-LSS system. Parameters that can be varied are: frequencies of the system response; weights of the OTV, propellant, and payload; size of the payload; engine rise time; and time lag between thrusters. Due to the method in which the problem was modeled, the location of the thruster must stay in the region of 20% of the radius of the LSS. Therefore, this program can only be used for the purpose of varying the lag time and determining its effect on FD. It can not be used to compare the effect of different thruster locations. The problem was modeled as follows:

At any given instant we have



This results from the thruster on the right firing an instant before the left thruster (therefore, it has a higher thrust level). This situation occurs only at times 0 to ~ the rise time of the engines. After that time both are at equal thrust levels of one-half the total thrust. This situation can be divided into two cases:



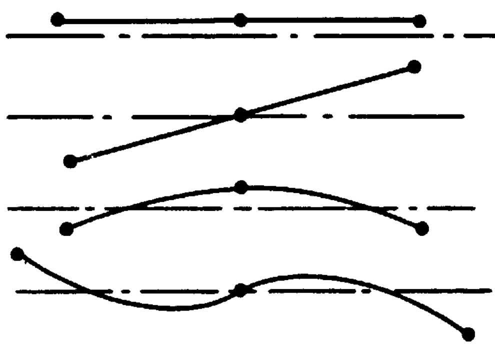
Superimposing above cases gives:

left side: $$\frac{F_L + F_R}{2} - \frac{F_R - F_L}{2} \equiv F_L$$

right side: $$\frac{F_L + F_R}{2} + \frac{F_R - F_L}{2} \equiv F_R$$

For each case (symmetric and antisymmetric), two modes are modeled: rigid-body mode and one elastic mode.

Modes:



symmetric, rigid-body

antisymmetric, rigid-body

symmetric, elastic

antisymmetric, elastic

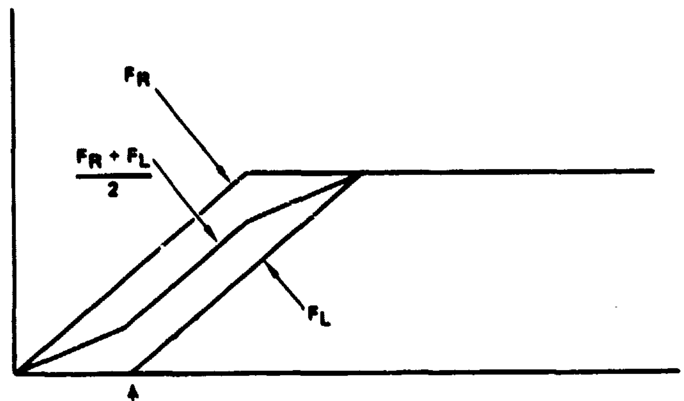
symmetrical force: $$F\langle t\rangle = \frac{F_R + F_L}{2}$$

antisymmetric force: $$F\langle t\rangle = \frac{F_R - F_L}{2}$$

FORCING FUNCTIONS

SYMMETRICAL: $F\langle t\rangle = \dfrac{F_R + F_L}{2}$

THRUST

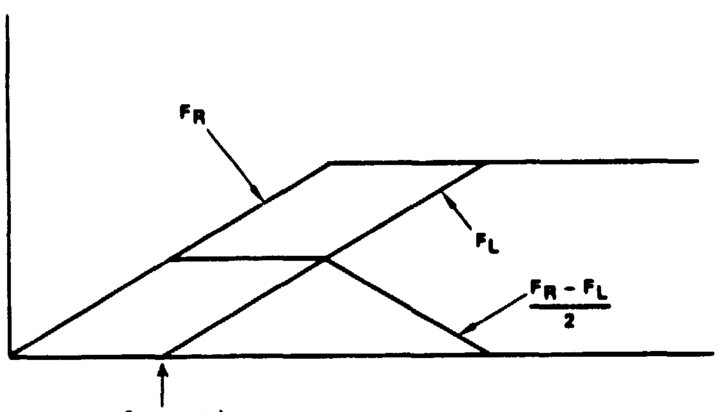


t = lag time

TIME

ANTISYMMETRICAL: $F\langle t\rangle = \dfrac{F_R - F_L}{2}$

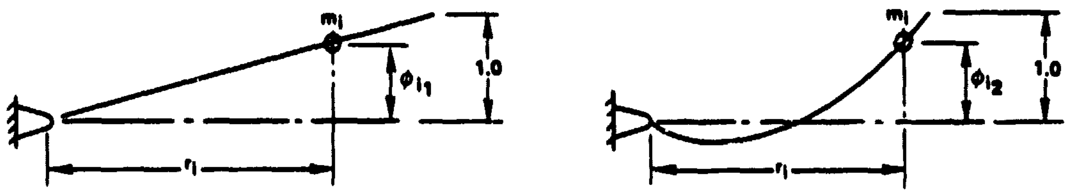
THRUST



t = lag time

TIME

ANTISYMMETRIC CASE:



Mode "1" Mode "2"

q_1 = ref. defl. due to Mode 1

q_2 = ref. defl. due to Mode 2

X_i = total defl. of M_i

$$X_i = \phi_{11} q_1 + \phi_{12} q_2$$

F_i = external force applied to M_i

Equations of note as in matrix form are:

$$\begin{bmatrix} M_{11} & 0 \\ 0 & M_{22} \end{bmatrix} \begin{Bmatrix} \ddot{X}_1 \\ \ddot{X}_2 \end{Bmatrix} + \begin{bmatrix} k_{11} & k_{12} \\ k_{21} & k_{22} \end{bmatrix} \begin{Bmatrix} X_1 \\ X_2 \end{Bmatrix} = \begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix}$$

In shorthand this is written:

$$[M] \{\ddot{X}\} + [k] \{X\} = \{F\} \qquad (1)$$

Let $[\phi] = \begin{bmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{bmatrix}$ = Model matrix (1A)

where ϕ_{ij} = modal displacement of M_i in mode j

$$\left[\omega^2\right] = \begin{bmatrix} \omega_{11}^2 & 0 \\ 0 & \omega_{22}^2 \end{bmatrix} = \text{frequency matrix}$$

Let $\{X\} = [\phi] \{q\}$ (2)

substitute (2) into (1)

$$[M] [\phi] \{\ddot{q}\} + [k] [\phi] \{q\} = \{F\}$$

Premultiply thru by $[\phi]^T$

where

$$[\phi]^T = \text{transpose of } [\phi] = \begin{bmatrix} \phi_{11} & \phi_{21} \\ \phi_{12} & \phi_{22} \end{bmatrix}$$

So that

$$[\phi]^T [M][\phi]\{\ddot{q}\} + [\phi]^T [k][\phi]\{q\} = [\phi]^T \{F\}$$

It can be proved that

$$[\phi]^T [M] [\phi] = \lceil \mathfrak{m} \rfloor \quad \text{a diagonal matrix} \qquad (2A)$$

$$[\phi]^T [k] [\phi] = \lceil \mathfrak{K} \rfloor \quad \text{a diagonal matrix}$$

$$\lceil \mathfrak{m} \rfloor \{\ddot{q}\} + \lceil \mathfrak{K} \rfloor \{q\} = \{\mathfrak{F}\}$$

where

$$\{\mathfrak{F}\} = [\phi]^T \{F\} \qquad (3)$$

Premultiply by $\lceil \mathfrak{m} \rfloor^{-1}$

$$\{\ddot{q}\} + \lceil \mathfrak{m} \rfloor^{-1} \lceil \mathfrak{K} \rfloor \{q\} = \lceil \mathfrak{m} \rfloor^{-1} \{\mathfrak{F}\}$$

It can be proved that

$$\lceil \mathfrak{m} \rfloor^{-1} \lceil \mathfrak{K} \rfloor = \lceil \omega^2 \rfloor \quad \text{a diagonal matrix}$$

whence

$$\lceil \omega^2 \rfloor = \begin{bmatrix} \omega_1^2 & 0 \\ 0 & \omega_2^2 \end{bmatrix}$$

$$\omega_i = \text{Nat-freq in mode } i$$

where

$$\{\ddot{q}\} + \lceil \omega^2 \rfloor \{q\} = \lceil \mathfrak{m} \rfloor^{-1} \{\mathfrak{F}\} \qquad (4)$$

Eq. 4 can be written out in detail as follows:

Mode "1" Eq: $\ddot{q}_1 + \omega_1^2 q_1 = \dfrac{\mathfrak{F}_1 \langle t \rangle}{\mathfrak{m}_{11}}$ (5)

Mode "2" Eq: $\ddot{q}_2 + \omega_2^2 q_2 = \dfrac{\mathfrak{F}_2 \langle t \rangle}{\mathfrak{m}_{22}}$ (6)

$\mathfrak{F}_i$ = "generalized force" in Mode i (find from Eq (3)

q_i = "generalized coordinate" in Mode i

Solve Eqs (5) and (6) for $q_1 \langle t \rangle$, $q_2 \langle t \rangle$

Use Eq (2) to get $X_1 \langle t \rangle$ and $X_2 \langle t \rangle$.

Foregoing has assumed $\left[\omega^2\right]$ and $[\emptyset]$ are known.

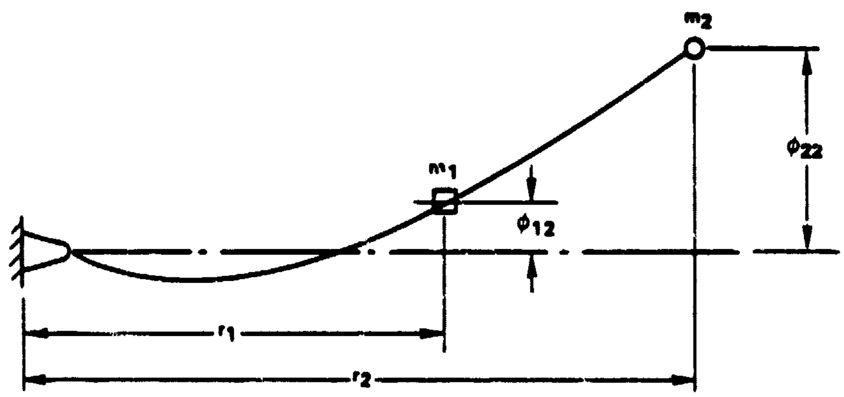
For mode (1) $\emptyset_{i1}$ is a linear function of r.

For mode (2) apply the boundary condition that d'Alembert moment about pivot point (i.e., ℄) is zero.

i.e.,

$$\sum_i M_i \, \emptyset_{i2} \, r_i = 0 \tag{7}$$

Consider a two-mass beam, as follows:



Eq. (7) gives:

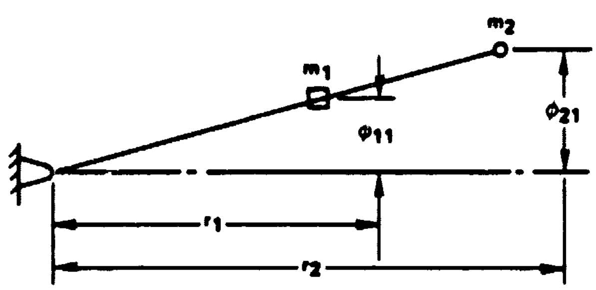
$$M_1 \, \emptyset_{12} \, r_1 + M_2 \, \emptyset_{22} \, r_2 = 0$$

$$\frac{\emptyset_{12}}{\emptyset_{22}} = - \frac{M_2 r_2}{M_1 r_1} \tag{8}$$

i.e.,

$\emptyset_{12}$ and $\emptyset_{22}$ <u>MUST</u> be of of opposite sign for this particular case.

Similarly for Mode 1



From geometry of rigid-body motion

$$\frac{\phi_{11}}{\phi_{21}} = \frac{r_1}{r_2} \tag{9}$$

<u>Let</u> $\phi_{21} = 1$

$\phi_{22} = 1$ i.e., ref. values at tip:

Then, from Eqs (1A), (8) and (9) we get

$$[\phi] = \begin{bmatrix} \frac{r_1}{r_2} & -\frac{M_2 r_2}{M_1 r_1} \\ 1 & 1 \end{bmatrix} \tag{10}$$

For chosen values of r_1/r_2, M_1/M_2 Eq (10) gives $[\phi]$. This is exact for a massless beam carrying two concentrated masses as shown.

An eigen value solution is needed for more complicated structures.

Now consider $\left\lceil \omega^2 \right\rfloor = \begin{bmatrix} \omega_1^2 & 0 \\ 0 & \omega_2^2 \end{bmatrix}$

ω_1 = rigid body mode = 0

ω_2 = elastic mode = any chosen value.

Note: Period = T = $\frac{2\pi}{\omega}$ seconds.

So we may say in summary:

$$\left\lceil \omega^2 \right\rfloor = \begin{bmatrix} 0 & 0 \\ 0 & \left(\frac{2\pi}{T}\right)^2 \end{bmatrix} \tag{11}$$

$$[\phi] = \begin{bmatrix} r_1/r_2 & -\frac{M_2\ r_2}{M_1\ r_1} \\ 1 & 1 \end{bmatrix} \tag{12}$$

$$\{X\} = [\phi]\{q\}$$

$$\{\ddot{X}\} = [\phi]\{\ddot{q}\} \qquad (12A)$$

$$\{\mathfrak{F}\} = \begin{Bmatrix} \mathfrak{F}_1 \\ \mathfrak{F}_2 \end{Bmatrix} = [\phi]^T \{F\} = \begin{bmatrix} r_1/r_2 & 1 \\ \dfrac{-M_2\ r_2}{M_1\ r_1} & 1 \end{bmatrix} \begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix}$$

Let $F_1 \langle t \rangle$ = engine thrust acting on M_1

$F_2 \langle t \rangle = 0$

Then

$$\mathfrak{F}_1 \langle t \rangle = \frac{r_1}{r_2} F_1 \langle t \rangle + {}_0\!\!\not{F}_2 \langle t \rangle \qquad (13)$$

$$\mathfrak{F}_2 \langle t \rangle = -\frac{M_2 r_2}{M_1 r_1} F_1 \langle t \rangle + {}_0\!\!\not{F}_2 \langle t \rangle \qquad (14)$$

Mass matrix is

$$[m] = \begin{bmatrix} M_1 & 0 \\ 0 & M_2 \end{bmatrix} \qquad (15)$$

Substitute (15) and (12) into (2A) to get generalized mass matrix, thus:

$$[m] = \begin{bmatrix} \dfrac{r_1}{r_2} & 1 \\ \dfrac{-M_2 r_2}{M_1 r_1} & 1 \end{bmatrix} \begin{bmatrix} M_1 & 0 \\ 0 & M_2 \end{bmatrix} \begin{bmatrix} \dfrac{r_1}{r_2} & \dfrac{-M_2 r_2}{M_1 r_1} \\ 1 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} M_1 \dfrac{r_1}{r_2} & M_2 \\ \dfrac{-M_2 r_2}{r_1} & M_2 \end{bmatrix} \begin{bmatrix} \dfrac{r_1}{r_2} & -\dfrac{M_2 r_2}{M_1 r_1} \\ 1 & 1 \end{bmatrix}$$

$$
= \begin{bmatrix} \left(M_1 \dfrac{r_1{}^2}{r_2{}^2} = M_2 \right) & ; & \left(-M_2 + M_2 \right) \\ \left(-M_2 + M_2 \right) & ; & \left(\dfrac{M_2{}^2 \; r_2{}^2}{M_1 r_1{}^2} + M_2 \right) \end{bmatrix}
$$

$$
\left[\mathfrak{m} \right] = \begin{bmatrix} M_2 \left(\dfrac{M_1}{M_2} \dfrac{r_1{}^2}{r_2{}^2} + 1 \right) & ; & 0 \\ 0 & & M_2 \left(\dfrac{M_2 r_2{}^2}{M_1 r_1{}^2} + 1 \right) \end{bmatrix} \qquad (16)
$$

Comparing (12) and (16) we can see that (16) can be written

$$
\left[\mathfrak{m} \right] = \begin{bmatrix} \left(M_1 \; \phi_{11}{}^2 + M_2 \; \phi_{21}{}^2 \right) & ; & 0 \\ 0 & ; & \left(M_1 \; \phi_{12}{}^2 + M_2 \; \phi_{22}{}^2 \right) \end{bmatrix} \qquad (17)
$$

Eqs (11), (12), (13), (14) and (17) give values of

$\left[\omega^2 \right]$, $\left[\phi \right]$, $\left[\mathfrak{F} \right]$, and $\left[\mathfrak{m} \right]$ in term of M_1, M_2, F_1 & ω_2

$\therefore$ They can be found numerically.

Substituting in (5) and (6) we have two linear differential equations in $q_1 \langle t \rangle$ and $q_2 \langle t \rangle$.

Initial conditions:

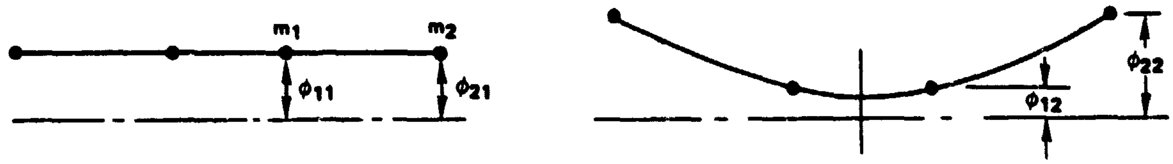
$$
t = 0 \qquad q_1 \langle t \rangle = 0 \qquad \dot{q}_1 \langle t \rangle = 0
$$

$$
q_2 \langle t \rangle = 0 \qquad \dot{q}_2 \langle t \rangle = 0
$$

Solve for $\ddot{q}_1 \langle t \rangle$ and $\ddot{q}_2 \langle t \rangle$.

Use Eq (12A) to get $\ddot{X}_1 \langle t \rangle$ and $\ddot{X}_2 \langle t \rangle$.

SYMMETRIC CASE:



rigid mode

elastic mode

For rigid-body mode (by inspection)

$$\phi_{11} = 1$$

$$\phi_{21} = 1$$

for elastic mode there must be no resultant force $\therefore$

B.C. is $M_1 \phi_{12} + M_2 \phi_{22} = 0$

$$\frac{\phi_{12}}{\phi_{22}} = -\frac{M_2}{M_1}$$

$$[\phi] = \begin{bmatrix} 1 & \frac{-M_2}{M_1} \\ 1 & 1 \end{bmatrix}$$

$$[\phi]^T \; [M] \; [\phi] = \left[m \right]$$

$$[\phi] = \begin{bmatrix} 1 & \frac{-M_2}{M_1} \\ 1 & 1 \end{bmatrix}$$

$$[M] = \begin{bmatrix} M_1 & 0 \\ 0 & M_2 \end{bmatrix}$$

$$[m] = \begin{bmatrix} M_1 + M_2 & 0 \\ 0 & \dfrac{M_2^{\,2}}{M_1} + M_2 \end{bmatrix}$$

$$\{\mathfrak{F}\} = \begin{Bmatrix} \mathfrak{F}_1 \\ \mathfrak{F}_2 \end{Bmatrix} = [\phi]^T \{F\}$$

$$= \begin{bmatrix} 1 & \dfrac{-M_2}{M_1} \\ 1 & 1 \end{bmatrix}^T \begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix}$$

F_1 = Force on M_1

F_2 = Force on M_2 = 0

$$\mathfrak{F}_1 = F_1 + F_o/2$$

$$\mathfrak{F}_2 = \frac{-M_2}{M_1} F_1 + F_o/2$$

FREQUENCIES

	Mode 1 (Rigid)	Mode 2 (Elastic)
Sym	$\omega_1 = 0$	ω_2
Anti Sym	$\omega_2 = 0$	$1.5 \times \omega_2$

$\ddot{X}_1 = \phi_{11}\, q_R + \phi_{12}\, q_e$ = accel mass 1

$\ddot{X}_2 = \phi_{21}\, q_R + \phi_{22}\, q_e$ = accel mass 2

Compute for both symmetric and antisymmetric case

add $\ddot{X}_1$ (sym) + $\ddot{X}_1$ (antisym) for accel of M_1

$\ddot{X}_2$ (sym) + $\ddot{X}_2$ (antisym) for accel of M_2

Differential eq's solved by Laplace Transforms.

Distributed Thrust Computer Program

"DISTR2"

```
10    IMAGE D.D,7X,D.DD,7X,D.DD
20    INTEGER I,J
30    SHORT Fr(61),Fl(61),Fs(61),Fa(61),Fg(61),Fgsr(61),Fgse(61),Fgar(61)
40    SHORT Fgae(61),Ax1(61),Ax2(61),Sa(4),Ss(4),Ba(4),Bs(4),S(4),B(4)
50    SHORT Axs1(61),Axs2(61),Axa1(61),Axa2(61),Mg11s,Mg22s,Mg11a,Mg22a
60    SHORT P11s,P12s,Ws,P11a,P12a,Wa
70    COM Lag,Tau,INTEGER I1,I2,I3
80    L=200
90    Motv=6000/32.2
100   Mprop=0
110   Mpl=16000/32.2
120   R1=.20*L
130   R2=.75*L
140   M1=.5*(Motv+Mprop)+.25*Mpl
150   M2=.25*Mpl
160   Ws=.5*2*3.14159
170   Wa=1.5*Ws
180   P11s=1
190   P12s=-M2/M1
200   P21s=1
210   P22s=1
220   P11a=R1/R2
230   P12a=-M2*R2/(M1*R1)
240   P21a=1
250   P22a=1
260   Fmax=1000
270   REM DIVIDE BY TWO SINCE MAX PER THRUSTER IS HALF THAT:
280   Fmax=Fmax/2
290   Mg11s=M1+M2
300   Mg22s=M2^2/M1+M2
310   Mg11a=M1*P11a^2+M2*P21a^2
320   Mg22a=M1*P12a^2+M2*P22a^2
330   REM
340   FOR Tau=.3 TO .7 STEP .20
350   REM
360   FOR Lag=0 TO .20 STEP .1
370   REM
380   FOR T=0 TO 6 STEP .1
390   I=10*T
400   F=Fmax
410   IF T<=Tau THEN F=Fmax/Tau*T
420   Fr(I)=F
430   J=I-10*Lag
440   Fl(I)=0
450   IF T<Lag THEN GOTO 470
460   Fl(I)=Fr(J)
470   Fs(I)=(Fr(I)+Fl(I))/2
480   Fa(I)=(Fr(I)-Fl(I))/2
490   REM
500   Fgsr(I)=Fs(I)
510   Fgse(I)=-M2/M1*Fs(I)
520   Fgar(I)=R1/R2*Fa(I)
530   Fgae(I)=-(M2*R2)/(M1*R1)*Fa(I)
540   NEXT T
550   REM
560   REM DETERMINE SLOPE AND "B" FOR DETERMINING SOL'N TO q.. + W^2*q = St + B
570   REM FORCING FUNCTION (Fg) CHANGES AT TIMES Lag,Tau,Lag+Tau
580   REM DETERMINE I FOR THESE TIMES:
590   REM
600   I1=INT(10*Lag)
610   I2=INT(10*Tau)
620   I3=INT(10*(Lag+Tau))
630   REM FOR SYMMETRIC CASE:
640   CALL Sb(Fgse(*),Ss(*),Bs(*),Mg11s,Mg22s)
650   REM FOR ANTISYMMETRIC CASE:
660   CALL Sb(Fgae(*),Sa(*),Ba(*),Mg11a,Mg22a)
```

```
670   REM CALL THE SUBROUTINE WHICH COMPUTES THE DESIRED ACCELERATIONS FOR
680   REM   EITHER SYMMETRIC OR ANTISYMMETRIC CASE:
690   REM
700   REM SYMMETRIC CASE:
710   CALL Accel(Fgsr(*),Fgse(*),Axs1(*),Axs2(*),Ss(*),Bs(*),P11s,P12s,Ws,Mg11s,
Mg22s)
720   REM ANTISYMMETRIC CASE:
730   CALL Accel(Fgar(*),Fgae(*),Axa1(*),Axa2(*),Sa(*),Ba(*),P11a,P12a,Wa,Mg11a,
Mg22a)
740   PRINT
750   PRINT "THRUST RISE TIME=";Tau;"TIME LAG BETWEEN ENGINES=";Lag
760   PRINT "   T    FD (mass1)    FD (mass2) "
770   FOR T=0 TO 6 STEP .1
780   I=10*T
790   IF T=0 THEN GOTO 820
800   Steady=Fr(I)/(.5*(Motv+Mpl+Mprop))
810   PRINT USING 10;T;(Axa1(I)+Axs1(I))/Steady;(Axa2(I)+Axs2(I))/Steady
820   NEXT T
830   REM
840   REM
850   NEXT Lag
860   REM
870   NEXT Tau
880   END
890   SUB Sb(SHORT Fg(*),S(*),B(*),Mg11,Mg22)
900   COM Lag,Tau,INTEGER I1,I2,I3
910   IF Lag=0 THEN GOTO 1010
920   S(1)=Fg(I1)/Mg22/Lag
930   S(2)=(Fg(I2)-Fg(I1))/Mg22/(Tau-Lag)
940   S(3)=(Fg(I3)-Fg(I2))/Mg22/Lag
950   S(4)=0
960   B(1)=0
970   B(2)=Fg(I1)/Mg22
980   B(3)=Fg(I2)/Mg22
990   B(4)=Fg(I3)/Mg22
1000  GOTO 1090
1010  S(1)=Fg(I3)/Mg22/Tau
1020  S(2)=Fg(I3)/Mg22/Tau
1030  S(3)=Fg(I3)/Mg22/Tau
1040  S(4)=0
1050  B(1)=0
1060  B(2)=0
1070  B(3)=0
1080  B(4)=Fg(I3)/Mg22
1090  SUBEND
1100  REM
1110  REM
1120  SUB Accel(SHORT Fgr(*),Fge(*),Ax1(*),Ax2(*),S(*),B(*),P11,P12,W,Mg11,Mg22)
1130  COM Lag,Tau,INTEGER I1,I2,I3
1140  SHORT Q(61),Qdot(61)
1150  P21=1
1160  P22=1
1170  Y=0
1180  Qic=0
1190  Qicdot=0
1200  FOR T=0 TO 6 STEP .1
1210  I=T*10
1220  X=T-Y
1230  IF I<=I1 THEN J=1
1240  IF (I>I1) AND (I<=I2) THEN J=2
1250  IF (I>I2) AND (I<=I3) THEN J=3
1260  IF I>I3 THEN J=4
1270  Q(I)=S(J)*(W*X-SIN(W*X))/W^3+B(J)*(1-COS(W*X))/W^2+Qic*COS(W*X)+Qicdot*SIN
(W*X)/W
1280  Qdot(I)=S(J)*(1-COS(W*X))/W^2+B(J)*SIN(W*X)/W-W*Qic*SIN(W*X)+Qicdot*COS(W*
X)
```

```
1290  REM
1300  IF I=I1 THEN GOTO 1340
1310  IF I=I2 THEN GOTO 1390
1320  IF I=I3 THEN GOTO 1440
1330  GOTO 1490
1340  Y=Lag
1350  Qic=Q(I)
1360  Qicdot=Qdot(I)
1370  GOTO 1490
1380  REM
1390  Y=Tau
1400  Qic=Q(I)
1410  Qicdot=Qdot(I)
1420  GOTO 1490
1430  REM
1440  Y=Tau+Lag
1450  Qic=Q(I)
1460  Qicdot=Qdot(I)
1470  GOTO 1490
1480  REM
1490  REM
1500  Aqr=Fgr(I)/Mg11
1510  Aqe=Fge(I)/Mg22-W^2*Q(I)
1520  Ax1(I)=P11*Aqr+P12*Aqe
1530  Ax2(I)=P21*Aqr+P22*Aqe
1540  NEXT T
1550  SUBEND
```

APPENDIX 13

COSTS

Table 1.4-1. Total Program Cost Definition.

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
100	ORBITAL TRANSFER VEHICLE TOTAL PROGRAM COST	This element is the total cost of the Orbital Transfer Vehicle Program. It is the summation of the three major program phases: Cost Element Number — Phase 1000 — Design, Development, Testing and Evaluation 2000 — Production 3000 — Operations Included are all labor, material and overhead required for the design, development, fabrication, required assembly, testing and operation of the OTV. Each phase is further subdivided into lower level cost elements which represent specific program tasks, functions or hardware elemtns. A fourth group of cost elements is First Unit Cost (Cost Element 4000). This grouping represents the theoretical first unit cost of production and is separated from the production phase because it is useful in computing other costs in both the production and DDT&E phases.

Table 1.4-2. DDT&E Phase Definitions

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1000	DDT&E PHASE	This cost element includes the cost to develop the Orbital Transfer Vehicle beginning with the conceptual and definition activities and concluding when the vehicle elements are ready for operational use. Included is the design, development and test of the flight hardware elements and associated ground and airborne support. Tooling, personnel training, systems engineering, facilities, software and program management are also included. It involves the application of scientific and engineering effort to transform an operational need into an operational system possessing the desired performance parameters. An iterative process of definition, synthesis, analysis, design, test and evaluation is utilized. Included in the effort is the integration of related technical parameters to assure compatibility of all physical, functional and program interfaces and to optimize the total system definition and design; along with the integration of reliability, maintainability, safety, human and other such factors into the total engineering effort. In addition to design and development of the airborne vehicle elements, costs include the acquisition of all ground equipment, and facilities necessary to support the vehicle development, and tooling necessary for production of test vehicles.
 1010 1020	FLIGHT HARDWARE - FIRST STAGE SECOND STAGE	This is the cost to design and develop all flight vehicle hardware, both reusable and expendable. The hardware elements are divided into 2 vehicle stages. Stage 1 represents the first stage hardware in a single stage, two stage, or 1-1/2 stage vehicle. Stage 2 includes the hardware in the second stage in a 2 stage vehicle or the drop tanks in a 1-1/2 stage vehicle.

Table 1.4-2. DDT&E Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1011	STRUCTURES	This cost element refers to the cost of designing and developing the OTV Structural Subsystem. Included are all direct and indirect labor costs, material and subcontract costs and all overhead elements related to the engineering design and analysis and procurement, test and evaluation of components and subsystems in this category. Also included are procurement and evaluation of mock-ups, special test rigs, and all other supporting engineering activities.
1011-1 1021-1	LH_2 TANK	This is the cost to design and develop the liquid hydrogen tank in a vehicle stage or drop tank. Includes both integral and nonintegral type tanks and also any support struts which provide structural support between the propellant tank and the shell or adapter surfaces.
1011-2 1021-2	LO_2 TANK	This is the cost to design and develop the liquid oxygen tank in a vehicle stage or drop tank. Includes both integral and nonintegral type tanks and also any support struts which provide structural support between the propellant tanks and the shell or adapter structures.
1011-3 1021-3	SHELL/BODY	This element is the design and development cost of the major load carrying structural entities on which the propellant tanks and the main engines mount. It includes the shell structure (comprised of forward skirt, main shell and intertank skirt), forward interface ring, manipulator attach point, access provisions and bracketing. The thrust structure which is the major load bearing element for the main engine is also included. It is comprised of engine mounting provisions, thrust struts, actuator attach points and mounting supports for engine fluid and electrical interface lines.

Table 1.4-2. DDT&E Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1011-4 1021-4	PAYLOAD/DOCKING ADAPTERS	This element is the design and development cost of skirts or adapters attached to the OTV shell or propellant tanks. Includes such items as payload, forward, and aft adapters as well as all mechanical attaching and securing devices used for docking or payload attachment.
1011-5 1021-5	AEROSURFACES	This cost element refers to the design and development of the aerodynamic structural surfaces of the OTV which may be required for an aeromaneuvering/braking OTV. Includes all surfaces which have an aerodynamic shape such as wings, stabilizers, fins, fairings and control surfaces. Also includes control and deployment mechanisms associated with the aerodynamic surfaces. Excludes those aerodynamic surfaces which are an integral part of the thermal protection system.
1011-6 1021-6	OTHER	Includes the design and development cost of other structure not included in the above categories.
1012 1022	THERMAL CONTROL SYSTEM	This cost element refers to the cost of designing and developing the OTV Thermal Control Subsystem. Includes all direct and indirect labor costs and overhead elements related to the engineering design, analysis, procurement, test and evaluation of components and subsystems in this category. The thermal control system consists of both active and passive means of controlling heat transfer within the OTV system. Thermal control devices or provisions which are an inherent part of a component of another subsystem are included within that subsystem and are excluded from this element.
1012-2 1022-2	ACTIVE	Refers to the design and development cost of such items as heaters, radiators, active louvers, heat pipes and cold plates. It also includes the insulation purge system including bottles, valves, disconnects, plumbing and regulators.

Table 1.4-2. DDT&E Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1012-2 1022-2	PASSIVE	Refers to the design and development cost of the thermal protection system cover panels, insulation, reinforcements, release mechanisms, fairings, attach structure, bonding material and local ablators. It also includes multi-layer type insulation for the propellant tanks and associated hardware.
1012-3 1022-3	OTHER	This element is not defined and is reserved for Thermal Control elements not contained in the above definitions.
1013 1023	AVIONICS	This element refers to the design and development cost of the avionics subsystems defined below. These costs include all direct and indirect prime and subcontractor labor, materials, G&A, and fee. Costs also include component and subsystem checkout and test costs at the subcontractor level.
1013-1 1023-1	GUIDANCE AND NAVIGATION	Includes design and development cost for all sensor, prime reference, computation, and data processing elements for this function. Includes cost of central computers, even though they may provide services for the data management and other subsystems.
1013-2 1023-2	COMMUNICATIONS	This is the design and development cost for: (1) RF, optical or other data links to the Shuttle, Space Station and other spacecraft, and (2) ground communications of data acquisition systems including voice, data, T.V. or other communication functions.
1013-3 1023-3	DATA MANAGEMENT	Includes design and development cost of all data conditioning, data processing and data recording elements. Also includes data management computer if the function is separate from the Guidance and Navigation computer.

Table 1.4-2. DDT&E Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1013-4 1023-4	INSTRUMENTATION	This element summarizes the cost of designing and developing the instrumentation equipment. It includes the required sensors, transducers and circuitry to monitor environmental conditions aboard the OTV within any of the subsystems. It also includes the design and development of the propellant utilization (PU) and propellant loading instrumentation (PLIS) system. The system consists of the controls which minimize the residual weight of one propellant at the depletion of the other. It consists of PU tank probes, LO_2 and LH_2 tank sensors and engine servopositioners to control propellant flow to the engines. This element excludes the computational and data conditioning devices.
1014 1024	POWER SUPPLY AND DISTRIBUTION	Cost to design and develop the prime energy source and the power conversion, conditioning and distribution systems. Inlcudes all direct and indirect prime and subcontractor labor, materials, G&A and fee.
1014-1 1024-1	POWER SOURCE	The element refers to the cost to design and develop the prime power source: solar array, battery or fuel cell. The solar array includes the cost of the support structure and the solar array, including solar cells and substrate. Battery development consists only of those costs associated with the battery and excludes other interfacing systems. Fuel cell development includes the costs of the fuel cell and associated plumbing and valves.
1014-2 1024-2	CONVERSION AND DISTRIBUTION	This element refers to the design and development costs for the distribution and control of electric power in the OTV. Included are such elements as generators, transformers, inverters, voltage regulators, buses, relays and switches.
1015 1025	PROPULSION	This element refers to the cost of designing and developing the OTV and OTV drop tank main engines and engine support systems. It includes all propulsion and vehicle contractor direct and indirect labor, material and overhead costs. Integrated testing at the vehicle system level is excluded.

Table 1.4-2. DDT&E Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1015-1 1025-1	MAIN ENGINE SYSTEM	This element refers to the costs of all activities necessary to develop rocket engines through the qualification milestone, and includes all engineering, and development activities, test hardware and engines, test operations and propellants consumed by the engine contractor in this activity. (Does not include "cluster" testing of complete engine system installation, any activities at vehicle contractor or engines to support vehicle test.)
1015-2 1025-2	PROPELLANT FEED, FILL & DRAIN	This element is the cost of all lines, valves, ducts, bellows and other components that transfer the oxidizer/fuel from the tanks to the main engine. Also included are all lines, ducts, valves, and other components required to fill and drain the main propellant tanks between the interface panel with the Orbiter or deployment adapter and the main tanks which are filled and drained.
1015-3 1025-3	THRUST VECTOR CONTROL	This element consists of the cost of the thrust vector control power conversion and distribution system elements and such other mechanisms or components as are required to orient and control the thrust vector of the main engine. It includes engine actuators and the associated valve controls or switches.
1015-4 1025-4	PRESSURIZATION AND VENT SYSTEM	This element is composed of all lines, valves, ducts, bellows and other components that take pressurization gases from the engine to the main fuel tank, and the lines, valves, ducts, bellows, storage tank and other components which provide pressurization gas to the oxidizer tanks. It also consists of those components that are required to provide for propellant vent and for carrying

(continued)

Table 1.4-2. DDT&E Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1015-4 Cont'd. 1025-4	PRESSURIZATION AND VENT SYSTEM (Continued)	pressurization gas for the main oxidizer and main fuel tanks for dumping propellant overboard. Also included are those provisions requireu to provide gas purge of required vehicle areas.
1015-5 1025-5	DROP TANK SOLID ROCKETS	This is the cost to design and develop the solid rocket motors. Includes test hardware and test activities of the engine contractor. Excludes vehicle contractor system test costs.
1016 1026	ATTITUDE CONTROL	This element refers to the cost of all activities necessary to develop an attitude control system. Engines, thrusters and propellant feed system are included. Computational and Sensing devices which control the orientation control hardware are contained in the Avionics category.
1016-1 1026-1	THRUSTER	This element covers the cost of all tasks, hardware and services necessary to design, develop and qualify the attitude control system engines.
1016-2 1026-2	TANKAGE/PROPELLANT FEED	This element includes the design and development of the attitude control system propellant tanks, propellant lines and valves.

Table 1.4-2. DDT&E Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1040	SYSTEM ENGINEERING AND INTEGRATION	This is the cost to define the engineering requirements necessary to direct an integrated approach to design, development and operations. Includes requirements definitions, mission payload analyses, preliminary design, design integration, system optimization, interface compatibility, design reviews, technical risk assessment, technical performance assessment, countdown analysis and system engineering data. Integration activities include intersystem engineering interface tasks with contractors and government agencies. Definition of Interface Control Documents, joint operating plans and interface control plans. Also includes development of program plans and analyses for: quality control, reliability, maintainability, producibility, transportability, safety, logistics and mass properties.
1050	INITIAL TOOLING	Includes the cost of planning, design, fabrication, assembly, installation, modification, maintenance and rework of all tools, including assembly tools, dies, jigs, fixtures, master forms, gauges and handling equipment for manufacturing use. Includes costs for the determination of tool requirements, planning of fabrication and assembly operations, maintaining tool records, scheduling and controlling all tooling orders, programming and preparation of tapes for numerically controlled machine parts, and preparation of templates and patterns.
1060	SYSTEM TEST	Refers to the cost of performing system development tests of the Orbital Transfer Vehicle. Includes test operations as well as the hardware necessary to perform the tests.

Table 1.4-2. DDT&E Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1061	TEST HARDWARE	Refers to costs of all major units of hardware purchased or fabricated in the DDT&E Phase for all system tests or flight demonstration. Includes production cost of test vehicles and airborne support equipment hardware for the launch vehicle.
1061-1	GROUND TEST	Includes the cost of manufacturing major vehicle subsystems and complete vehicle elements needed for structural/dynamic testing, avionics system tests, propulsion system integration testing and all systems testing. Mock-ups and hardware for subsystem test and qualification are excluded from this element but are included with their design and development costs, as are special purpose test rigs. Propellants and gases are to be included with Ground Test Operations and excluded here. Includes one set of ASE.
1061-2	FLIGHT TEST	Includes the manufacturing cost of all test articles required for the flight test program such as the launch vehicle drop tanks and airborne support equipment. (1 set)
1062	TEST OPERATIONS	Includes the costs of performing development tests using prototype hardware to acquire engineering data and confirm engineering hypotheses. The test operations include the detail planning, conduct, support, data acquisition and analysis, reports and materials consumed in ground, and flight tests.
1062-1	GROUND TEST	Includes the cost of structural testing (static, hydrostatic, fatigue, dynamic, etc.) as well as all propulsion system testing and vehicle hot firing or cluster testing, propellant loading system tests, thermal vacuum testing, functional tests of the deployment adapter and launch site facility verification tests.

Table 1.4-2. DDT&E Phase Definition (continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1062-2	FLIGHT TEST	Includes the operations cost of supporting the flight test program to test ascent and on-orbit characteristics of the OTV. A dedicated test flight is a vehicle flight for test purposes only and does not carry an operational payload. It includes all activities that support such test flight programs from the planning to launch, actual flight and return. All OTV and OTV/Shuttle interface systems launch support, operations support (i.e., countdown, tracking, etc.) data analysis and evaluation are included. Propellants and gases are also included. Excluded are activities associated with flights that carry an operational payload. These are to be included under the appropriate operational elements even though the flight may, as a secondary purpose, serve as a test flight.
1070	AIRBORNE SUPPORT EQUIPMENT	This element includes the cost to design and develop the equipment required to support the operation of the OTV in orbit. It summarizes tasks and services required to mate the OTV with the Shuttle, link with and separate from it. Included is the equipment for operational docking/undocking of the OTV and Shuttle, abort provisions, alignment and energy absorption, retraction/extension support, reentry purge, avionics interface, umbilical disconnects in the fluid/electrical interface, and on-orbit assembly tools and equipment. Production cost included underground test and flight test (1 set each).
1071	STRUCTURAL AND MECHANICAL	This element summarizes tasks, hardware and services required to design, develop and test structural and mechanical OTV/Shuttle interface equipment. This equipment consists of structural/mechanical portions of items required for OTV deployment, rendezvous and docking; interface panels, OTV/Orbiter supports, and supports for interfacing subsystems.

Table 1.4-2. DDT&E Phase Definition (continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1072	FLUID SYSTEMS	This element summarizes tasks, hardware and services required to design, develop and test the OTV/Shuttle interface fluid subsystems. These items consist of main propellant fill, drain, dump, vent and purge provisions between the OTV and Shuttle and through the Shuttle and similar Attitude Control propellant provisions as required. Task includes qualification test of components and subsystems.
1073	ELECTRICAL/ AVIONICS	This element summarizes tasks, hardware and services to design, develop, test, produce, install and check out the electronic and electrical equipment that provides OTV/Shuttle interfaces while the OTV is in the Orbiter payload bay and while it is entering or leaving it during a mission. Task includes qualification test of components and subsystems.
1074	OTHER	This element summarizes tasks, hardware and services to design, develop and test other airborne support equipment which is not yet defined but includes the hardware items and tools necessary to assemble the OTV on-orbit.
1080	GROUND SUPPORT EQUIPMENT	Includes the cost of development engineering, testing and production of all ground-based equipment required to support the launch, recovery, and maintenance phases of the vehicles during flight test operations, flight operations or mission operations. Covered are scientific and engineering services related to research efforts, development and reliability work integral to equipment design. Costs for the testing of ground equipment consist of the conduct of the test, manufacture of mockups, test rigs, instrumentation and unique test equipment. Test (Continued)

Table 1.4-2. DDT&E Phase Definition (continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1080 (continued)	GROUND SUPPORT EQUIPMENT	equipment common to the test of ground equipment and air vehicle are considered as part of facilities costs. Production costs of ground equipment, tooling and engineering support effort and material are included here. Ground equipment is normally delivered to the launch and operations site.
1090	FACILITIES AND EQUIPMENT	Costs for facilities include those incurred in the procurement and preparation of land; construction and/or modification of structures; installation of equipment, tools, cranes and derricks; service roads; railroad tracks; utilities, etc. Includes costs for such facilities as: vehicle and engine test; launch; operational and maintenance; manufacturing; and facility activation.
1100	SOFTWARE	This element consists of the costs incurred in developing, analyzing, verifying and implementing the OTV and OTV/Shuttle interface software, both ground and airborne. It includes system and program design; program coding and debugging; program testing; and integration of programs.
1101	FLIGHT VEHICLE SOFTWARE	This element consists of the cost of tasks and services required to incorporate the software for OTV onboard systems.
1102	SHUTTLE INTERFACE SOFTWARE	This element consists of the cost of tasks and services required to incorporate OTV generated software requirements into Shuttle subsystems or subsystems which remain with the Shuttle during the OTV portion of the missions.

Table 1.4-2. DDT&E Phase Definition (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1103	GSE SOFTWARE	This element consists of the cost of tasks and services required to incorporate OTV related software into the ground support equipment at the manufacturing, refurbishment and launch sites.
1104	MISSION CONTROL SOFTWARE	This element consists of the cost of tasks and services required to incorporate OTV related software into the ground mission control systems.
1110	TRAINING	Refers to the cost of instruction programs for Orbital Transfer Vehicle flight and ground crews as well as the associated simulators and equipment.
1111	PERSONNEL TRAINING	Refers to the cost of training both ground and flight crews to support the Orbital Transfer Vehicle Program. Excludes cost of simulators.
1111-1	FLIGHT CREW TRAINING	Includes the cost of instruction, audio and visual teaching aids, physical training, simulated mission training, parts and accessories required to train flight crew personnel to fly the orbital transfer vehicles or to provide on-orbit support for the OTV. Also included is the cost to determine training requirements and planning of the training program.

Table 1.4-2. DDT&E Phase Definition (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
1111-2	GROUND CREW TRAINING	Includes the cost of instruction, audio and visual teaching aids, parts and accessories required to train ground crew personnel to maintain the orbital transfer vehicles and to support missions. Also included is the cost to determine training requirements and planning of the training program.
1112	SIMULATORS AND EQUIPMENT	Includes the design, development and manufacture of those distinctive end items of equipment designed specifically to meet training objectives such as operational and maintenance trainers, cutaways, mockups and models. Facilities costs constructed exclusively for the training mission are included here.
1120	PROGRAM MANAGEMENT	Refers to the costs associated with the prime contractor's centralized effort in areas of program planning, control and administration. Includes such tasks as program documentation, financial and manpower control, interfacing with the customer and other contractors and material and project management.

Table 1.4-3. First Unit Cost Definitions.

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
4000	FIRST UNIT	Describes the cost of manufacturing the first orbital transfer vehicle production unit. It includes the cost of hardware manufacturing, integration, assembly and checkout for all the vehicle stages, whether expendable or reusable, and the expendable hardware for the first unit. All costs include the direct and indirect labor, material and overhead required to produce the first unit. Contractor fee is excluded.
4100	OTV FLIGHT HARDWARE	Refers to the cost of producing the first unit hardware for the orbital transfer vehicle. The hardware elements are divided into 2 vehicle stages. Stage 1 represents the first stage hardware in a single stage, two stage or 1 1/2 stage vehicle. Stage 2 includes the hardware in the second stage of a 2-stage vehicle or the drop tanks in a 1 1/2 stage vehicle.
4110 4120	STAGE 1 STAGE 2	These elements include the cost of producing the first production units of Stage 1 and 2. Includes the fabrication assembly, checkout and integration of the Structures, Thermal Control, Avionics, Power Supply and Distribution, Propulsion, and Attitude Control systems of each stage.
4111 4121	STRUCTURES	These cost elements refer to the cost of producing the first unit of the structures system for Stage 1 and Stage 2. Physical elements of the individual structural elements are the same as those defined under cost elements 1011 and 1021 in the DDT&E phase, Table 2.
4112 4122	THERMAL CONTROL SYSTEM	These elements include the fabrication cost of the first production unit of the thermal control system for each OTV stage. Physical elements of this system are the same as those defined in Table 2 under cost elements 1012 and 1022.
4113 4123	AVIONICS	These cost elements represent the cost to manufacture the first avionics subsystem units for Stage 1 and Stage 2. Elements of the avionics subsystem are the same as previously defined in Table 2, under elements 1013 and 1023.
4114 4124	POWER SUPPLY AND DISTRIBUTION	Costs associated with the production of the first unit of the power supply and distribution system for each Stage. Physical elements of this system are the same as those defined in WBS categories 1014 and 1024 in Table 2.

Table 1.4-3. First Unit Cost Definitions (cont'd).

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
4115 4125	PROPULSION	These elements include the cost to fabricate the first production unit of propulsion for Stage 1 and Stage 2. Physical elements of this system are the same as those defined in Table 2 under cost elements 1016 and 1025.
4116 4126	ATTITUDE CONTROL	These elements refer to the cost of fabricating the first production unit of the attitude control subsystem for Stage 1 and Stage 2. Physical elements of this system are the same as those defined in Table 2 under cost elements 1016 and 1026.
4117 4127	INTEGRATION, ASSEMBLY CHECKOUT AND TEST	Refers to the contractor activities in integrating and assembling hardware elements and subsystems into an operational system. Includes all system calibration and checkout, as well as necessary acceptance testing.
4200	AIRBORNE SUPPORT EQUIPMENT	Refers to the cost of producing the first unit of equipment to support the OTV aboard the shuttle and in orbit. It includes all direct and indirect labor, material and overhead costs. This is the equipment for operational docking and undocking of the OTV and the Shuttle, abort provisions, alignment and energy absorption, retraction/extension support, avionics/electrical interface, fluids interface, including purge provisions, and the integration, assembly checkout and test of the complete assembly. Also includes the cost of on-orbit assembly tools and equipment.
4210	STRUCTURAL/ MECHANICAL	This cost element refers to the cost of producing the first unit of structural and mechanical interface equipment between the Shuttle and OTV. Includes items required for rendezvous and docking interface panels, OTV/Orbiter supports, and supports for interfacing systems.
4220	FLUID SYSTEMS	This element summarizes the tasks, hardware and services required to produce the first unit of the fluid systems hardware required to support the OTV in the Shuttle. Includes main propellant fill, drain, dump and vent and purge provisions between the OTV and Shuttle and through the Shuttle. Also includes similar Attitude Control provisions as required.

Table 1.4-3. First Unit Cost Definitions (cont'd).

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
4230	ELECTRICAL/ AVIONICS	This element summarizes tasks, hardware and services to produce the electronic and electrical equipment that provides OTV/Shuttle interfaces while the OTV is in the Orbiter payload bay and while it is entering or leaving it during a mission. Tasks include qualification test of components and subsystems.
4240	OTHER	This element includes the cost to produce the first unit of other airborne support equipment, such as the tools required for on-orbit assembly.
4250	INTEGRATION, ASSEMBLY, CHECKOUT AND TEST	Refers to the cost of integrating and assembling ASE hardware elements and subsystems into an operational system. Includes system calibration checkout and acceptance testing.

Table 1.4-4. Production Phase Definitions.

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
2000	PRODUCTION PHASE	Refers to that portion of the OTV program where fleet vehicles and expendable hardware is fabricated. The facilities, ground equipment, airborne support equipment and tooling are acquired during DDT&E to accommodate all necessary production and operational launch rates. The costs of all reusable or expendable orbital transfer vehicles and expendable elements required to support the operational fleets are included. The costs of all necessary support and management are also included. Production costs include all direct and indirect labor, material and overhead. Contractor fee is excluded. Includes all costs associated with the procurement and manufacture of the main stages and drop tanks of the orbital transfer vehicle fleet. The hardware elements are divided into 2 vehicle stages. Stage 1 represents the first stage hardware in a single stage, two stage or 1 1/2 stage vehicle. Stage 2 includes the hardware in the second stage of a 2-stage vehicle or the drop tanks in a 1 1/2 stage vehicle.
2100 2200	STAGE 1 STAGE 2	These elements include the direct and indirect costs of manufacturing the OTV stages in quantities required to accommodate operational program requirements. The cost elements contained under these categories refer to the cost of manufacturing new vehicle stages in quantities to support the operations phase of the OTV program. They include the manufacture and assembly of all hardware in the structures, thermal control, avionics, power supply and distribution, propulsion and attitude control subsystems. The integration of these subsystems into a single entity, checkout and test of the final product is also included.
2300	R&D VEHICLE MODIFICATIONS	Includes the cost to inspect and appropriately modify flight test vehicles or the flight demonstration articles of the orbital transfer vehicle that are to be included in the operational fleet.

Table 1.4-4. Production Phase Definitions (cont'd).

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
2400	INITIAL SPARES	Includes the manufacturing cost of spare parts for the initial spares stock required for vehicle operations.
2500	SUSTAINING TOOLING	Includes the cost of tooling maintenance, replacement, modification and rework needed in support of new vehicle manufacturing.
2600	ENGINEERING SUPPORT	Includes the cost of engineering effort that is in direct support of manufacturing. Involves the coordination of the various manufacturing activities on an inter-departmental basis and with subcontractors and vendors. Also includes continued engineering analysis of test results and other supporting activities (product improvement).
2700	PROGRAM MANAGEMENT	Refers to prime contractor costs associated with providing a central direction and control of the overall orbital transfer vehicle program. Includes program planning, scheduling, budgeting, monitoring and control, documentation, coordination and other program management activities.

Table 1.4-5. Operations Phase Definitions.

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
3000	OPERATIONS PHASE	This phase covers the operational period of the Orbital Transfer Vehicle program. In this portion of the life cycle the finished product is put into operation and is maintained in an operating condition for the duration of the program, or replaced. It includes all direct and indirect labor, materials (spares) and propellant costs required to operate and maintain the vehicles, facilities and equipment developed & produced in the DDT&E and Production Phases. The operations phase is divided into three major divisions of work: ground based operations, space based operations and logistics support.
3100	GROUND BASED OPERATIONS	Refers to the costs incurred in operating and providing the ground based services of: integrating the OTV into the Shuttle, tracking, command and control, vehicle recovery and maintenance of the OTV. Also includes cost of training replacement personnel and program management of the operations phase.
3110	PRELAUNCH	This cost element includes all material, labor and services necessary for pre-flight ground operations phase of the program. It includes checkout of the OTV and installation of the mated OTV and payload into the orbiter.
3120	COMMAND AND CONTROL	Includes cost associated with ground command, control and tracking from vehicle launch through mission completion and return. Includes such functions as flight control, telemetry communications, data processing and data analysis. Excludes those activities which are included in the standard Shuttle user charge.
3130	POST MISSION OPERATIONS	This activity will involve OTV safing at space shuttle landing, removal of OTV from the space shuttle bay and flight deck at the Operational Payload Facility, moving of the OTV to the operations and checkout building for postmission processing which includes maintenance, disassembly, refurbishment storage, or shipping as appropriate.

Table 1.4-5. Operations Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
3140	MAINTENANCE AND REFURBISHMENT	This element refers to the labor and overhead costs for maintaining the OTV, OTV support hardware and OTV facilities in an operating condition. Includes both the recurring scheduled and unscheduled maintenance costs for the vehicle, ASE, GSE and Facilities. This element also summarizes the efforts for refurbishing and restoring the reusable OTV to a readiness condition. Cost of material and replacement parts is included under Cost Element 3410.
3141	Vehicle	This element refers to the cost of performing regular scheduled maintenance and major overhaul at specified intervals on the OTV subsystems. Also includes the cost of unscheduled, or unplanned, maintenance or servicing to return the OTV to an operable condition. Cost of replacement parts is covered under Cost Element 3410.
3142	ASE	This element refers to the cost of performing regular scheduled maintenance and unscheduled, or unplanned, maintenance for the airborne support equipment. Cost of replacement parts is covered under Cost Element 3420.
3143	GSE	This element refers to the cost of maintaining the OTV ground support equipment in an operable condition. Includes the cost of both scheduled and unscheduled maintenance. Cost of replacement parts is included under Cost Element 3430.

Table 1.4-5. Operations Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
3144	FACILITIES	This activity is the cost of the effort required to maintain the OTV facilities and equipment in good operating condition.
3150	REPLACEMENT TRAINING	Includes the cost of training qualified flight and ground crew personnel to replace those lost by rotation or attrition in order to maintain manned at levels necessary to meet flight and ground operation schedules.
3160	IN-PLANT ENGINEERING & TECHNICAL SUPPORT	This element consists of the costs of the sustaining engineering effort required during the operations phase. A principal effort includes engineering changes to the OTV which result from system operational experience or user recommendation. The element also encompasses engineering for mission peculiar changes, software maintenance, launch support activities and technical management.
3170	PROGRAM MANAGEMENT	Refers to the costs associated with the management of the operations phase. Includes such items as: (1) Program administration and management, including budgeting, monitor and control. (2) Planning and scheduling of flights, and (3) Financial and administrative support.

Table 1.4-5. Operations Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
3200	SPACE BASED OPERATIONS	Refers to the operation of a space based orbital transfer vehicle. Includes cost of the astronaut crew required to operate the OTV if it is a manned version and they reside at a permanent space station. Also includes all maintenance operations which are performed in space. Includes costs of maintenance/refurbishment crew as well as the transportation costs of ferrying the crew from earth to orbit or from one orbit to another. Transportation costs of logistics support for space based Orbital Transfer Vehicles are also included.
3210	SPACE BASED CREW	This element refers to all direct and indirect costs for OTV crews which reside at a permanent station in space.
3220	MAINTENANCE/ REFURBISHMENT	This element includes all transportation and crew costs required for OTV maintenance and refurbishment performed in space and the cost of transporting the crew to and from space to perform maintenance/refurbishment activities.
3221	CREW	This the direct and indirect cost of the OTV maintenance and refurbishment crew who perform work on the OTV on-orbit.
3222	TRANSPORTATION	This element refers to the cost of Shuttle transportation in transporting maintenance crews to and from space or from orbit to orbit.
3230	SPARES TRANSPORTATION	Refers to the cost to transport spares into orbit for subsequent use in the OTV. This would normally be accomplished by tanker mode Shuttle flights.

Table 1.4-5. Operations Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
3240	PROPELLANT TRANSPORTATION	Refers to the cost to transport peopellants and gases into orbit for subsequent use by the OTV. This would normally be accomplished by tanker mode Shuttle flights.
3300	LOGISTICS SUPPORT	Refers to the recurring costs of manufacturing and stocking spare parts and propellants during the operational phase. Does not include maintenance/ refurbishment labor costs.
3310	FOLLOW-ON SPARES	Includes the costs of spare parts and components produced to replenish initial spare stocks in support of OTV maintenance and overhaul, both scheduled and unscheduled.
3311	STRUCTURES	Includes the spares cost of all structural elements such as tank, shell and adapters.
3312	THERMAL CONTROL	This element refers to the spares cost for the thermal control system.
3313	AVIONICS	This element includes all spares costs related to the avionics subsystem.
3314	POWER SUPPLY & DISTRIBUTION	Includes the spares costs for the OTV power supply and distribution system.

Table 1.4-5. Operations Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
3315	PROPULSION	This element includes the cost to stock spares for the OTV propulsion system. It includes the main engine, propellant feed, fill and drain, and thrust vector control.
3316	ATTITUDE CONTROL	This element refers to the cost of spares used in the overhaul and maintenance of the attitude control system.
3320	PROPELLANTS AND GASES	Refers to the costs of propellants and gases used by the OTV fleet during the operations phase, both for prelaunch testing and for flight.
3321	PROPELLANTS	Includes propellants used for each flight plus allowance for losses and testing.
3322	GASES	Includes all gases used for each flight plus allowance for losses and testing.
3400	SHUTTLE BASED OPERATIONS	This element refers to the costs of all activities stemming from the use of the Space Shuttle under the following conditions: (1) Putting an OTV stage into orbit; (2) Assembling OTV stages or drop tanks on-orbit to make an operational unit; (3) Retrieving reusable OTV elements for return to earth for ground maintenance/refurbishment. Includes Shuttle transportation charges for transferring the OTV to orbit, specialized Shuttle crew costs, OTV crew costs, and other Shuttle related operations.

Table 1.4-5. Operations Phase Definitions (Continued)

COST ELEMENT NUMBER	COST ELEMENT DESIGNATION	DEFINITION
3410	BASIC SHUTTLE USER CHARGE	This element refers to the cost of using the Space Shuttle in OTV deployment or retrieval from orbit. Includes the basic charge for standard Shuttle flights plus any additional charges such as extended on-orbit stay time or special provisions.
3420	CREW	Includes the direct and indirect costs of a specialized Shuttle crew who are responsible for deploying, assembling and retrieving the OTV from orbit. Also includes the cost of manned OTV crews when the flight originates from the Shuttle rather than a permanently manned station in space. This element excludes the cost of a standard Shuttle crew. This is covered under the standard Shuttle User Charge in Element 3210.
3430	OTHER	This element includes all charges for the Shuttle performing an OTV deployment, assembly or retrieval operation not covered in Elements 3210 or 3220.

TOTAL PROGRAM COST COMPUTER PRINTOUTS

10.38.47. 04/28/80

LOW THRUST OTV - 37K EXPENDABLE, 25 UNITS PROD/LAUNCHED

OTV COST MODEL

NEW DESIGN ; 17,000 # P/L CAPABILITY

UDT+E PHASE 1000 -TOTAL-				536.60
1010 FLIGHT HARDWARE - STAGE 1			292.62	
1011 STRUCTURES		54.56		
-1 LH2 TANK	11.81			
-2 LO2 TANK	26.08			
-3 SHELL/BODY	11.82			
-4 PAYLOAD/DOCKING ADAPTERS	4.85			
-5 AEROSURFACES				
-6 OTHER				
1012 THERMAL CONTROL SYSTEM		16.73		
-1 ACTIVE	15.56			
-2 PASSIVE	1.17			
-3 OTHER				
1013 AVIONICS		53.00		
-1 GUIDANCE + NAVIGATION	27.63			
-2 COMMUNICATIONS	2.57			
-3 DATA MANAGEMENT	21.92			
-4 INSTRUMENTATION	.88			
1014 POWER SUPPLY + DISTRIBUTION		11.06		
-1 POWER SOURCE	6.59			
-2 CONVERSION + DISTRIBUTION	4.46			
1015 PROPULSION		146.25		
-1 MAIN ENGINE SYSTEM	117.00			
-2 PROP FEED, FILL + DRAIN	20.99			
-3 THRUST VECTOR CONTROL	3.50			
-4 PRESSURIZATION + VENT SYS	4.76			
-5 DROP TANK SOLID ROCKET				
1016 ATTITUDE CONTROL		11.02		
-1 THRUSTER	2.99			
-2 TANKAGE/PROPELLANT FEED	8.03			

Avionics -
Components are 40% off-
the-shelf

1040 SYSTEM ENG • INTEGRATION			46.[illegible]
1050 INITIAL TOOLING			3.31
1060 SYSTEM TEST			122.12
1061 TEST HARDWARE		44.11	
-1 GROUND	27.00		
-2 FLIGHT	17.11		
1062 TEST OPERATIONS		78.01	
-1 GROUND	47.06		
-2 FLIGHT	30.95		
1070 AIRBORNE SUPPORT EQUIPMENT			14.28
1071 STRUCTURE/MECHANICAL		3.43	
1072 FLUID SYSTEMS		6.01	
1073 ELECTRICAL/AVIONICS		4.05	
1074 OTHER			
1080 GROUND SUPPORT EQUIPMENT			21.18
1090 FACILITIES • EQUIPMENT			
1100 SOFTWARE			10.[illegible]1
1101 FLIGHT VEHICLE		4.96	
1102 SHUTTLE INTERFACE		2.45	
1103 GSE		.91	
1104 MISSION CONTROL		2.45	
1110 TRAINING			3.64
1111 PERSONNEL		1.00	
-1 FLIGHT			
-2 GROUND	1.00		
1112 SIMULATORS		2.64	
1120 PROGRAM MANAGEMENT			22.71

1.75 Ground Test Units + 1 … A.E.
1 Flight Test Unit + 1 … A.E.
Ground Tests : Propulsion System
Structural
Fatigue/Vibration
Deployment … Functional
Avionics Functional
Thermal Vacuum
Launch Site Facilities …
Flight test operations includes … a dedicated shuttle for $25.4 million
GSE – Development plus 3 sets.

ORIGINAL PAGE IS OF POOR QUALITY

FIRST UNIT 4000 -TOTAL-					17.11	
OTV FLIGHT HARDWARE 4100				13.19		
4110 STAGE 1			13.19			
4111 STRUCTURES		1.41				
-1 LH2 TANK	.28					
-2 LO2 TANK	.67					Toroidal Lox Tank
-3 SHELL/BODY	.40					
-4 PAYLOAD/DOCKING ADAPTERS	.06					
-5 AEROSURFACES						
-6 OTHER						
4112 THERMAL CONTROL SYSTEM		1.01				
-1 ACTIVE	.76					
-2 PASSIVE	.25					
-3 OTHER						
4113 AVIONICS		4.29				
-1 GUIDANCE + NAVIGATION	1.63					unmanned avionics
-2 COMMUNICATIONS	1.79					
-3 DATA MANAGEMENT	.75					
-4 INSTRUMENTATION	.12					
4114 POWER SUPPLY + DISTRIBUTION		1.49				
-1 POWER SOURCE	1.30					Modified Shuttle fuel cells + 1 backup battery
-2 CONVERSION + DISTRIBUTION	.20					
4115 PROPULSION		2.63				
-1 MAIN ENGINE SYSTEM	.99					New Low Thrust (1000#) engine
-2 PROP FEED, FILL + DRAIN	1.03					
-3 THRUST VECTOR CONTROL	.10					
-4 PRESSURIZATION + VENT SYS	.50					
-5 DROP TANK SOLID ROCKET						
4116 ATTITUDE CONTROL		1.18				
-1 THRUSTER	.46					
-2 TANKAGE/PROPELLANT FEED	.72					
4117 INT. ASSY. CO + TEST		1.18				

	AIRBORNE SUPPORT EQUIPMENT 4200		3.92
II	4210 STRUCTURE/MECHANICAL	.77	
	4220 FLUID SYSTEMS	1.83	
	4230 ELECTRICAL/AVIONICS	.95	
	4240 OTHER		
	4250 INT. ASSY. CO + TEST	.38	

PRODUCTION PHASE 2000 -TOTAL-				320.68
STAGE I 2100			219.64	
2110 STRUCTURES		21.56		
2111 LH2 TANK	4.25			
2112 LO2 TANK	10.29			
2113 SHELL/BODY	6.10			
2114 PAYLOAD/DOCKING ADAPTORS	.92			
2115 AEROSURFACES				
2116 OTHER				
2120 THERMAL CONTROL SYSTEM		11.88		
2121 ACTIVE	8.90			
2122 PASSIVE	2.98			
2123 OTHER				
2130 AVIONICS		84.57		
2131 GUIDANCE • NAVIGATION	32.15			
2132 COMMUNICATIONS	35.24			
2133 DATA MANAGEMENT	14.87			
2134 INSTRUMENTATION	2.31			
2140 POWER SUPPLY • DISTRIBUTION		29.42		
2141 POWER SOURCE	25.55			
2142 CONVERSION • DISTRIBUTION	3.88			
2150 PROPULSION		40.24		
2151 MAIN ENGINE SYSTEM	15.17			
2152 PROP FEED, FILL • DRAIN	15.72			
2153 THRUST VECTOR CONTROL	1.61			
2154 PRESS • VENT SYSTEM	7.74			
2155 DROP TANK SOLID ROCKETS				
2160 ATTITUDE CONTROL		18.11		
2161 THRUSTER	7.11			
2162 TANKAGE/PROPELLANT FEED	11.00			
2170 INT. ASSY. CO • TEST		13.87		

25 UNITS PRODUCED
\$12.83/unit avg

R&D UNIT MODIFICATIONS 2300	
INITIAL SPARES 2400	21.96
SUSTAINING TOOLING 2500	17.57
ENGINEERING SUPPORT 2600	43.93
PROGRAM MANAGEMENT 2700	17.57

OPERATIONS PHASE 3000 -TOTAL-				764.95
GROUND BASED OPERATIONS 3100			123.87	
3110 PRELAUNCH		2.00		
3120 COMMAND + CONTROL		53.90		
3130 POST MISSION OPERATIONS				
3140 MAINTENANCE/REFURBISHMENT		8.89		
3141 VEHICLE				
3142 ASE	4.90			
3143 GSE	3.99			
3144 FACILITIES				
3150 REPLACEMENT TRAINING		3.50		
3160 IN-PLANT ENG + TECH SUPPORT		47.26		
3170 PROGRAM MANAGEMENT		8.32		
SPACE BASED OPERATIONS 3200				
3210 SPACE BASED CREW				
3220 MAINTENANCE/REFURBISHMENT				
3221 CREW				
3222 TRANSPORTATION				
3230 SPARES TRANSPORTATION				
3240 PROPELLANT TRANSPORTATION				
LOGISTICS SUPPORT 3300			4.40	
3310 FOLLOW-ON SPARES		1.17		
3311 STRUCTURES	.07			
3312 THERMAL CONTROL	.13			
3313 AVIONICS	.54			
3314 POWER SUPPLY + DISTR.	.19			
3315 PROPULSION	.10			
3316 ATTITUDE CONTROL	.15			
3320 PROPELLANTS + GASES		3.24		
3321 PROPELLANTS	1.47			
3322 GASES	1.76			
SHUTTLE BASED OPERATIONS 3400			636.68	
3410 BASIC SHUTTLE USER CHARGE		635.00		
3420 CREW		1.68		
3430 OTHER				

25 units launched
$30.60/unit incl. shuttle
5.20/unit w/o shuttle

END
DATE
JAN. 8, 1981